

Sierra Nevada Network Vital Signs Monitoring Plan

Appendix F: Ecosystem Conceptual Models

Natural Resource Report NPS/SIEN/NRR—2008/072

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Introduction: Ecosystem Conceptual Models

This appendix presents the following information for the Sierra Nevada Network (SIEN) conceptual ecosystem models:

1. Purpose and goals of conceptual models
2. SIEN approach to model development
3. SIEN overview, system, process, and population models—encompassing Network vital signs

Conceptual models are working hypotheses about system form and function: they depict essential attributes of a system, express ideas about important components and processes, document assumptions, identify gaps in knowledge, and evolve to capture an increasing understanding of the system (Manley et al. 2000). Conceptual model development has been identified as a key component of a scientifically based monitoring plan (National Research Council 1995, Noon et al. 1999, National Park Service 2006). Conceptual models help in the design and interpretation of long-term monitoring by identifying important biotic and environmental features and processes, providing insight into potential cause-and-effect relationships, and establishing standard formats and concepts for communication of complex ideas (Roman and Barrett 1999). Conceptual models serve as communication tools among scientists from different disciplines, between scientists and managers, and between managers and the public.

Conceptual models can take the form of any combination of narratives, tables, matrices of factors, box-and-arrow diagrams, or conceptual diagrams. Jorgensen (1988) discusses 10 kinds of models and evaluates their advantages and disadvantages. We use a combination of these forms as a means to summarize and illustrate large quantities of information.

Purpose and Objectives

Conceptual models have served the following objectives in development of our monitoring program:

- Formalized current understanding of

ecosystem structure and function as well as relationships among ecosystem components at various levels of organization (landscape, community, watershed, population)

- Highlighted effects of important drivers and stressors on park resources and ecosystem processes
- Identified and articulated relationships among ecosystem attributes of interest and vital signs (indicators)
- Allowed for a shared vision to be created: facilitate communication among participants in the iterative process of vital signs identification, prioritization, selection, and protocol development
- Useful for integration and application—identify gaps, establish priorities, and solicit an agreed syntheses

As the Network progresses toward implementation of vital signs monitoring, the models will inform our thinking about sample design, facilitate integration and synthesis of data, and serve as communication tools about the program (Gross 2005). We hope that future models will assist us in communicating connections between management decisions and information gained from monitoring, such as identification of threshold conditions that could trigger a management action.

Approach to Conceptual Model Development

Development of models for the Sierra Nevada Network (SIEN) began with the Science Committee, during planning of Phases I and II of vital signs monitoring. Park, USGS and Network staff worked with a contractor to develop draft models that illustrated current understanding of key interactions among proposed vital signs and other ecosystem components and processes. These models helped inform vital signs prioritization processes, and, subsequently, the Science Committee's selection of a subset of vital signs for protocol development.

As we have progressed through Phases I, II and III of vital signs' monitoring planning, we have worked to organize—

what were initially disparate models—into a hierarchical framework, to standardize the format of systems models, and to learn from the approaches of other networks with similar ecosystems, ecosystem stressors, or monitoring interests (especially Rocky Mountain Network, Northern and Southern Colorado Plateau Networks, Mojave Network, and North Coast/Cascades Network).

We follow hierarchy theory, which provides a context for conceptualizing a complex system as a set of less complex sub-models spanning a range of scales and ecological levels (Allen and Hoekstra 1992). Our model framework (Table F- 1) is organized into:

1. Overview models: Our overview models provide context at broad spatial or temporal scales for Sierra Nevada ecosystem drivers, stressors, processes, and components.
2. System models: Our system models describe focal systems of interest for vital signs monitoring, and illustrate the core drivers, system components and functions, and major stressors influencing these systems.

Table F–1. Conceptual models included within this Appendix. Models are dynamic; as new relationships are elucidated, our models will evolve. Further, new models may be developed and included as part of our monitoring protocol development process.

| | MODEL | LOCATION |
|-----------------------------|--|-----------------------------|
| Overview | Sierra Nevada Ecosystems | Chapter 2 and <i>Within</i> |
| | Sierra Nevada Stressors | Chapter 1 and <i>Within</i> |
| | Landscape Exchange | Chapter 2 and <i>Within</i> |
| | Landscape Dynamics | <i>Within</i> |
| System, Process, Population | Atmospheric System Nitrogen Deposition | <i>Within</i> |
| | Hydrologic System | <i>Within</i> |
| | Aquatic System Lakes Amphibians Rivers and Streams | <i>Within</i> |
| | Wetland System Invertebrates | <i>Within</i> |
| | Forest System Fire Regimens | <i>Within</i> |
| | Non-native Invasive Plant Populations Invasion Susceptibility | <i>Within</i> |
| | Bird Populations | <i>Within</i> |

3. Detailed (process, population) models: Our detailed models explain key processes (e.g., fire regimes, nitrogen deposition) or organisms (e.g., invertebrates, anurans, non-native invasive plants, birds), illustrating relationships among system components and functions, drivers, and stressors.

Future Development and Applications of Models

As protocols are developed and implemented, the models can correspondingly evolve to capture an increasing understanding of the system. Monitoring results will be analyzed and interpreted, and resultant information will be shared with a variety of audiences. The Sierra Nevada Network may further develop conceptual models: for the following purposes:

- **Outreach & Communication:** Attractive, simple pictorial models that explain focal systems and relationships of components and drivers for interpretive applications, general audiences, web pages, etc.
- **Information Interpretation & Gap Identification:** complete models that elaborate more detailed relationships among components and drivers, capture and incorporate improved understanding from on-going research and monitoring projects, and identify specific gaps in understanding in various systems.
- **Prediction:** Predictive models that use actual data to identify areas most sensitive to climatic change, most vulnerable to non-native plant invasions, or most affected by nitrogen deposition and ozone pollution.
- **Simulation and analysis:** Mathematical, statistical, or null models that predict patterns of species diversity, niche overlap, and species co-occurrence. Some networks in the NPS are beginning to use modeling simulation programs such as EcoSim (Gotelli and Entsminger 2006).

The Network will need to consider modeling capability in its development of university partnerships and long-term network staffing, as conceptual and predictive modeling will be an integral

part of monitoring program development, data analysis and interpretation, and communication and outreach.

I. Overview Models

Below, we present four overview models to: (1) highlight ecosystem factors that interact with processes to structure the physical environment and its biotic communities, (2) depict stressors and synergistic effects, (3) illustrate inputs and outputs (i.e., exchanges of materials and organisms) that affect Sierra Nevada landscapes, and (4) highlight interactions of core drivers, stressors, and system components, as they apply to Sierran landscapes.

Overview Model: Sierra Nevada Ecosystems

SIEN has modified a general ecosystem model from Jenny (Jenny 1941) and Chapin et al. (Chapin et al. 1996) to serve as a foundation for our other models. This model (Figure F–1) presents ecosystem processes as a function of hierarchical state factors and interactive controls.

State factors operate at the largest (broadest) scales and include global climate, continental- and regional-scale topography, parent material (e.g., geologic substrate), time (e.g., age of the system), and the types and distributions of organisms within a landscape. Interactive controls—such as local climate patterns, soil function and development, and the type and distribution of organisms—both control and respond to ecosystem characteristics, and are constrained by state factors (Chapin et al. 1996, Dale et al. 2000). However, we modify the Jenny-Chapin model components in several ways to better represent Sierra Nevada park systems by:

- Adding “anthropogenic change” as another state factor that affects (a) most other state factors at a regional to global scale, and (b) affects the local interactive controls (please refer to Chapter 1 for a discussion of the major stressors associated with anthropogenic change in the Sierra Nevada).
- Adding “ecosystem processes” as an interactive control.

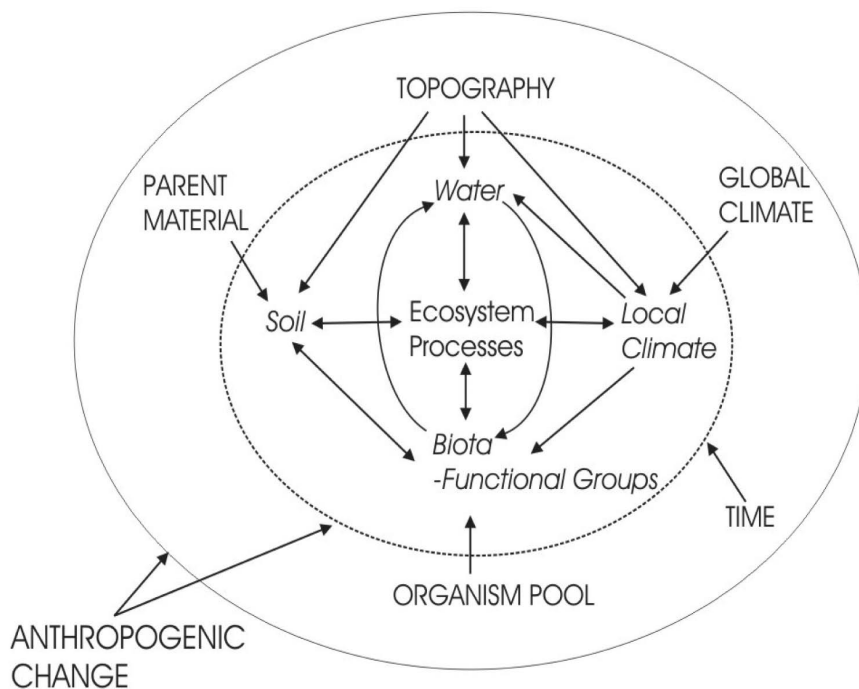


Figure F–1. Generalization model for Sierra Nevada ecosystems depicting the relationship among state factors, interactive controls, and ecosystem processes. See text for explanation. State factors are capitalized, interactive controls are italicized, the region (here=Network) is represented by the inner dotted-circle, and the Earth is represented by the solid circle.

- Omitting “disturbance regime” as an interactive control; instead, we place fire and flood disturbance regimes under “ecosystem processes” (we see these primarily as climate-driven processes of change that should not be considered separately from other ecosystem processes).
- Making “water” explicit as an interactive control to emphasize its critical role as a limited—and limiting—resource in our Mediterranean climate regime.

Table F–2 provides an overview of the functions and characteristics of interactive controls and ecosystem processes.

Table F–2. Definition of SIEN ecosystem model “interactive controls” and their characteristics and function. Definitions primarily from (Chapin et al. 1996).

| SIEN INTERACTIVE CONTROLS | CHARACTERISTICS AND FUNCTIONS OF INTERACTIVE CONTROLS |
|---|--|
| Climate strongly governs structure, productivity, and biogeochemistry of ecosystems | <ul style="list-style-type: none"> • Mediterranean: dry summers/wet winters • Affects dynamics of ecosystem processes, distribution of organisms, water availability |
| Soil resource supply determines maximum productivity and structural diversity of vegetation | <ul style="list-style-type: none"> • Characterized by physical structure and chemistry • Functions include nutrient cycling and availability, water availability and loss, microorganism habitat • Soil type and depth affect vegetation distribution |
| Water is a limiting resource in Mediterranean climate regimes; driver of productivity, abundance, and growth form | <ul style="list-style-type: none"> • Surface water, snowpack, soil & ground water • Characterized by temporal flow cycles, water quality; provides habitat for aquatic organisms and is driver for distribution of terrestrial organisms |
| Biota (i.e., functional groups) are groups of species that have similar effects on ecosystem processes | <ul style="list-style-type: none"> • Ecosystem productivity, nutrient cycling, carbon fixation, evapotranspiration, herbivory, predation, decomposition, pollination, biodiversity |
| Ecosystem Processes are flows of energy and materials in an ecosystem; climate-driven processes of change | <ul style="list-style-type: none"> • Climate-driven processes: fire, flood, avalanche • Biogeochemical cycling, plant productivity, erosion, weathering, population dynamics |

Overview Model: Sierra Nevada Stressors

Network park managers and researchers, using well-considered professional judgment, a substantial supporting body of research, and findings from the Sierra Nevada Ecosystem Project (SNEP 1996, Sequoia And Kings Canyon National Parks 1999b), have identified five important systemic stressors posing the greatest threat to Sierra Nevada Network parks. To reiterate and elaborate here, five systemic stressors currently pose the greatest threat to Sierra Nevada Network parks:

1. Rapid anthropogenic climate change
2. Altered fire regimes
3. Non-native invasive species
4. Air pollution
5. Habitat fragmentation and human use

Of these, rapid anthropogenic climatic change may have the greatest potential to affect ecosystems, in part because of its pervasiveness and extent across ecosystems, as well as synergistic effects with other stressors (Figure F- 2).

Conversely, localized stressors (e.g., vegetation trampling by livestock or park visitors, small dams and diversions, and mines) generally affect small areas of Sierra Nevada Network parks, although they might threaten special-status

species or alter rare habitats. These localized stressors and resource issues are discussed below.

The effects of the above systemic stressors on ecosystem biota and processes strongly influenced our selection of Network vital signs, indicators, and measures (see Chapter 3).

We characterize drivers as major external driving forces having large-scale influences on natural systems; drivers can be natural or anthropogenic. Network drivers include: atmospheric system, fire regime, and geology and topography (conceptual models, below). We characterize *anthropogenic* drivers as stressors.

Stressors are defined as physical, chemical, or biological perturbations to a system that are either (a) foreign to that system or (b) natural to the system but applied at an excessive [or deficient] level (Barrett et al. 1976:192). Stressors cause significant changes in the ecological components, patterns, and processes in natural systems.

Non-native invasive species (plants and animals, including pathogens) can severely alter plant community composition and structure, competition and predation, native plant and animal diversity, fire regime, and soil water dynamics.

Air pollution affects water and soil chemistry, forest population dynamics (e.g., reduced vigor), plant community composition, and may affect wildlife (e.g., endocrine disruption of amphibians). In addition, it may favor non-native plants through nitrogen deposition, and affects fuel availability for fire by affecting plant productivity.

Finally, human use and park fragmentation typically results in: habitat loss, altered fire regime, diversion of water, disruption to wildlife, increases in non-native species invasions and may degrade wilderness values (e.g., dark night sky, natural soundscape).

Climate Change

Climate change may have the greatest potential to affect ecosystems in part because it helps generate associative or synergistic effects which couple with other stressors, particularly—altered fire regime, air pollution, and non-native invasive plants. Climate change can affect critical ecosystem components and processes, including: entire forests and other plant communities; phenology of plants and animals; ranges of disease vectors; precipitation amounts, type and timing of natural events; snowpack; surface water dynamics; and hydrologic processes. Anthropogenic climate change might soon influence all other stressors and become the predominant stressor.

Average global temperatures have been rising, and the earth's atmosphere is warmer than at any point during the last several centuries (Mann et al. 1998). The present CO₂ concentration has not been exceeded during the past 420,000 years and likely not during the past 20 million years; the current rate of increase is unprecedented during at least the last 20,000 years. About three-quarters of anthropogenic emission of CO₂ to the atmosphere is due to fossil fuel burning; the rest is predominantly due to land-use change, especially deforestation (IPPC 2001, IPCC 2007).

There is broad international consensus among climatologists and atmospheric

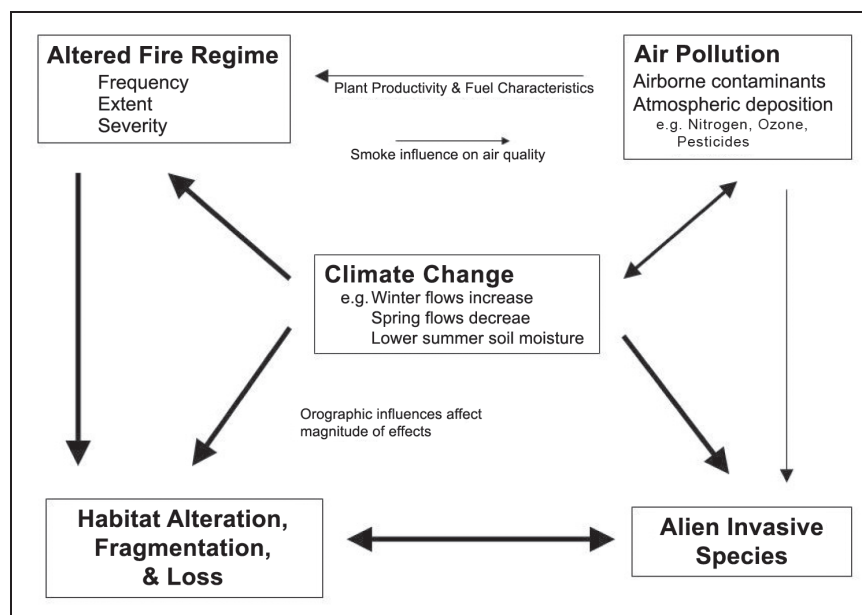


Figure F–2. Sierra Nevada stressors and associative, or synergistic, effects.

scientists that “most of the observed warming over the last 50 years is likely [attributable to a human-induced] increase in greenhouse gas [e.g., CO₂, from the burning of fossil fuel] concentrations” (Houghton et al. 2001). Global temperatures (and globally-averaged surface temperatures) are projected to increase another 1.4 to 5.8° C (2.5 to 10.4° F) over the next century—a rate probably unprecedented over the last 10,000 years (Houghton et al. 2001). This is expected to have profound effects on weather and climate.

The last several decades in the Sierra Nevada were among the warmest of the last millennium (Graumlich 1993). Recent simulations of climate change models suggest that by the years 2050 to 2100, average annual temperature in the Sierra Nevada could increase by as much as 3.8° C (6.8° F) (Snyder et al. 2002)—the equivalent of about an 800 m upward displacement in climatic zones. Average temperatures in May could increase by 9° C (16.2° F).

Paleoecological records show the early and middle Holocene (ca. 10,000 to 4,500 years ago) was a period of generally higher global summer temperatures, perhaps as much as 2° C (3.6° F) and prolonged summer drought in California. During this period, fire regimes and plant community composition of

Sierra Nevada forests differed from those of today (including some species combinations that no longer exist) (Anderson 1990, Anderson and Smith 1991, Anderson 1994, Anderson and Smith 1994, 1997). Although the past is an imperfect analog of the future, these and other paleo-ecological records indicate climatic change smaller than, or comparable to, those projected for the next century could profoundly alter Sierra Nevada ecosystems.

Phenological studies indicated that in much of the West, lilacs and honeysuckles are responding to the warming trend by blooming and leafing out earlier (Cayan et al. 2001).

Human-influenced temperature patterns are significantly associated with discernible changes in plant and animal (invertebrate, bird, amphibian, tree, shrub) phenological traits (Root et al. 2005).

Researchers predict that even a relatively modest 2.5° C (4.5° F) mean temperature increase would significantly alter precipitation, snow pack, surface water dynamics (e.g., flow), and hydrologic processes in the Sierra Nevada. The most pronounced changes would probably be earlier snowmelt runoff and reduced summer base flows and soil moisture (Dettinger et al. 2004, Dettinger 2005), a lower snowpack volume at midelevations (Knowles and Cayan 2001), and increased winter and spring flooding (Dettinger et al. 2004). Two climate models predict significant reductions in Sierra Nevada snowpack by the year 2100: one model predicts 30–70% reduction, the other a 73–90% reduction (Hayhoe et al. 2004).

Flows in many western streams begin a week to almost three weeks earlier than they did in the mid 20th century (Cayan et al. 2001, Dettinger 2005). There is also a trend towards slightly later precipitation (Dettinger 2005). Observed stream flow timing and winter-spring warming trends are consistent with current projections of how greenhouse effects may influence western climates and hydrology. Changes in precipitation type and timing may result in longer and drier summers, i.e., less water available during the months when it is

most needed (Dettinger 2005). Glacial extent in the Sierra Nevada has declined markedly in the past several decades.

Changes in Sierra Nevada climate related to precipitation quantity (e.g., snowpack) are less certain (Howat and Tulaczyk 2005). If current trends continue, researchers predict that natural reservoirs provided by snowpack will become progressively less useful for water resources management. A trend in the Sierra Nevada, towards smaller ratios of 'winter-total snowfall water equivalent' to 'winter-total precipitation', during the period 1949–2004, has already been documented (Knowles et al. 2006). If warming trends in our region continue, as projected in response to increasing greenhouse gas concentrations (IPCC 2007), the snowfall fraction of precipitation is likely to continue to decline (Knowles et al. 2006). In addition, flood risk may change in unpredictable ways and Sierra Nevada ecosystems may experience increasingly severe summer-drought conditions (Dettinger 2005, Dettinger et al. 2005, Mote et al. 2005). Prolonged summer drought alters natural fire regime and would increase the potential for high-severity wildfires and further threaten water quality.

The atmospheric concentration of carbon dioxide (CO₂) has increased by 31% since 1750. The present CO₂ concentration has not been exceeded during the past 420,000 years and likely not during the past 20 million years; the current rate of increase is unprecedented during at least the last 20,000 years. About three-quarters of anthropogenic emission of CO₂ to the atmosphere is due to fossil fuel burning; the rest is predominantly due to land-use change, especially deforestation (IPPC 2001).

It has been argued that the earth's biosphere (primarily, terrestrial biosphere) may have the capacity to sequester much of the increased carbon dioxide (CO₂) in the atmosphere associated with fossil fuel burning. This effect is termed "CO₂ fertilization" because, in the envisioned scenario, higher ambient CO₂ levels in the atmosphere literally fertilize plant growth. Further, because photosynthesis by plants

converts CO₂ into oxygen, it has been argued that “CO₂ fertilization” could potentially provide a strong negative feedback on changing CO₂ levels.

However, climatologists contend that as CO₂ concentration of the atmosphere increases, ocean and land will take up a decreasing fraction of anthropogenic CO₂ emissions. The net effect of land and ocean climate feedbacks as indicated by models will further increase projected atmospheric CO₂ concentrations, by reducing both the ocean and land uptake of CO₂ (IPCC 2001).

Some habitats (e.g., high alpine) may shrink dramatically or disappear entirely, leading to irreversible loss of some species (e.g., Clark’s Nutcracker, pika). Two climate models predict significant reductions in Sierra Nevada alpine-subalpine forest by the year 2100: one model predicts 50–75% reduction, the other a 75–90% reduction (Hayhoe et al. 2004).

Global climate change is also likely to exacerbate three other systemic stressors of the Sierra Nevada: altered fire regime, air pollution, and non-native invasive species. Some models predict future climate change will be accompanied by increased lightning strikes at latitudes spanned by the Sierra Nevada (Price and Rind 1991). Compounding the increase in wildfire ignitions, extreme weather conditions such as drought are likely to result in fires burning larger areas, being more severe, and escaping containment more frequently (Torn and Fried 1992, Miller and Urban 1999c). Warm temperatures create the perfect conditions for the production of smog and ground-level ozone. Global warming is therefore likely to make air pollution problems worse. A warmer climate would create conditions that would allow the expansion of species better adapted to such conditions.

Altered Fire Regimes

Altered fire regime significantly affects forests and other plant community composition and structure (e.g., increases in forest and shrub density). It can result in shifts in plant and animal species composition, including possible loss of fire-dependent species, and will almost certainly increase the probability of unnaturally severe fire. It influences presence of non-native invasive species, hydrology, water and soil chemistry, biogeochemical cycling and air quality.

From the late 1890s through 1960s, Sierra Nevada park and national forest personnel attempted to suppress all fires, and these efforts were mostly successful. Consequently, numerous ecosystems that had evolved with frequent fires have since experienced prolonged periods without fire (Swetnam et al. 1992, Swetnam 1993, Caprio and Graber 2000, Caprio et al. 2002, Caprio and Lineback 2002).

Change in fire regime has modified ecosystems. In foothill grasslands for example, lack of fire encourages dominance by non-native invasive grasses (Parsons and Stohlgren 1989). Reproduction of shade-intolerant species (e.g., giant sequoia) has been reduced (Harvey et al. 1980, Stephenson 1994). More land is dominated by dense, intermediate-aged forest patches, and less by young patches (Bonnicksen and Stone 1978, Vankat and Major 1978, Bonnicksen and Stone 1982, Stephenson 1987). Forests are denser, dominated by shade-tolerant species, and shrubs and herbaceous plants may be less abundant (Kilgore and Biswell 1971, Harvey et al. 1980). A buildup of surface fuels has accumulated (Agee et al. 1978, van Wagtendonk 1985) and increasing numbers of small trees have created “ladder fuels”, which carry fire into mature tree crowns (Kilgore and Sando 1975, Parsons and DeBenedetti 1979). These changes have led to a higher risk of high-severity wildfires than was present before European settlement and fire suppression activities (Kilgore and Sando 1975, Vankat 1977, Stephens 1995, Stephens 1998).

Lack of fire can affect water resources by reducing stream flows, altering biogeochemical cycling, and decreasing nutrient inputs to aquatic systems (Chorover et al. 1994, Williams and Melack 1997b, Hauer and Spencer 1998, Moore 2000). Less frequent but higher severity wildfires can also impair water resources, resulting in loss of vegetation cover, litter, and organic matter. The formation of these water repellent soil layers can affect evapotranspiration, infiltration, and snowmelt patterns (Helvey 1980, Inbar and Wittenberg 1998, DeBano 2000, Huffman et al. 2001). Potential impacts include increased flooding, erosion, sediment input, water temperatures, and nutrient and metal concentrations (Tiedemann et al. 1978, Helvey 1980, Riggan et al. 1994, Mac Donald and Stednick 2003, Heard 2005).

Lack of fire has reduced habitat (and food) critical for some wildlife species. Number and extent of forest openings have been reduced, which in turn has reduced key herbaceous and shrub species (e.g., nitrogen fixers such as *Ceanothus*) (Bonnicksen and Stone 1982). Wildlife that require these plants, such as deer, now have less habitat available.

In 1968 (Sequoia & Kings Canyon) and 1970 (Yosemite), NPS staff began prescribed burning. After more than 30 years of prescribed fires, significant progress has been made, although park efforts are far from restoring natural fire regimes at the landscape level (e.g., (Caprio and Graber 2000, National Park Service 2004).

Non-native Invasive Species

Non-native invasive species (plants and animals, including pathogens) can severely alter plant community composition and structure, competition and predation, native plant and animal diversity, fire regime, and soil water dynamics.

Plants

Some of the most widespread invasive grasses first arrived in California during the 16th century as propagules hitchhiking on explorers; their spread was subsequently exacerbated by grazing, drought, and burning by Native Americans (Hendry 1934, Heady et al. 1992).

Numerous invasive vascular plant species are present in Sierra Nevada parks. Despite management efforts, many are spreading and new invasions continue: at least 180 species now occur in Yosemite, 200 in Sequoia and Kings Canyon, and eight in Devils Postpile.

Herbaceous biomass of foothill grasslands in Sequoia is 99% invasive species (Parsons and Stohlgren 1989), and altered fire regime (i.e., a particular fire frequency, intensity, or seasonal distribution) may be one of the reasons (Parsons and Stohlgren 1989). Fire suppression has likely inhibited plant invasion into montane landscapes because closed canopy forests are not generally favorable sites for invasive plants. However, reintroduction of fire onto the landscape may promote establishment of invasive species, particularly in resultant light gaps or areas of high fire severity (Keeley 2001). Because plant species evolve—not in association with fire per se—but within a particular fire regime, some highly fire-adapted plant communities (e.g., chaparral) may be vulnerable to invasive competition (Keeley 2001). Also, the invasion process is affected by (1) the extent to which fires and fire management practices encourage establishment and spread, and (2) the degree to which such practices inhibit or reverse the invasion process (Keeley 2001). Concomitantly, the presence of invasive plant can lead to altered fire regimes, including increased fire frequency (Keeley 2001).

Invasive plants can severely alter ecosystems. They can alter soil water dynamics, thereby stressing native species and perhaps increasing the potential for invasion by noxious species such as yellow star-thistle (Gerlach 2004). Parts of Sequoia National Park that have been severely grazed by cattle (trespassing) now harbor numerous invasive species.

Animals

At least 30 invasive vertebrate species have been reported in Sequoia and Kings Canyon, and 21 have been reported in Yosemite. Many of these species (e.g., trout, bullfrog) are of concern to management because they may have deleterious effects on native wildlife populations.

The widespread introduction of brown, rainbow, and brook trout into high elevation lakes and streams has altered ecosystems, which were naturally without fish. Introduced fish and chytrid fungus are suspected of being leading factors in declines of native amphibian species in the Sierra Nevada, including the precipitous decline of the yellow-legged frogs (Bradford 1989, Bradford et al. 1993, Knapp and Matthews 2000, Rachowicz and Vredenburg 2004, Rachowicz et al. 2005, Rachowicz et al. 2006, Rachowicz et al. In press). Bullfrogs are voracious predators, and carriers of chytrid fungus. The full impact of bullfrogs on native species in the parks is unknown, but extirpation of California redlegged frog (federally threatened) from Yosemite is attributed to bullfrog presence (S. Thompson, Wildlife Biologist, Yosemite, pers. comm.). Domestic animal species (e.g., free-ranging house and feral cats) consume native species and compete with native wildlife for resources.

Air Pollution: Air Contaminants and Atmospheric Deposition

Air pollution affects water and soil chemistry, forest population dynamics (e.g., reduced vigor), plant community composition, and may affect wildlife (e.g., endocrine disruption of amphibians). In addition, it may favor nonnative plants through nitrogen deposition, and affects fuel availability for fire by affecting plant productivity.

The southern and central Sierra Nevada are subject to some of the worst air quality in the United States (Peterson and Arbaugh 1992, Cahill et al. 1996), particularly during the summer months. The San Joaquin Valley, west of the Sierra Nevada parks, is a trap for air pollutants originating in the valley as well as pollutants from cities along the central California coast that are carried in on prevailing winds. Southward-flowing air currents enter California at the San Francisco Bay and move through the valley until they reach the mountains at the southern end of the basin, causing an eddy to form in the vicinity of Visalia



Figure F-3. Air flow patterns in the San Joaquin Valley.

and Fresno, just west of the southern Sierra Nevada (Lin and Jao 1995) (Figure F-3). Thermal inversions frequently trap air over the valley at night during the summertime. Airborne pollutants are then transported into the mountains when this air rises during the day. As a result, Sequoia and Kings Canyon have some of the worst air quality found in any NPS unit in the country (Bradford and Gordon 1992, Cahill et al. 1996). Yosemite and Devils Postpile are also impacted, but to a lesser degree.

One of the most damaging air pollutants is ozone. Research suggests chronic ozone pollution can lead to shifts in forest structure and composition (Miller 1973). If current ozone concentrations remain relatively constant, or increase, they may affect the genetic composition of pine and sequoia seedling populations and contribute to increased susceptibility to fatal insect attacks, death rates, and decreased recruitment (Miller 1973, Ferrell 1996, Miller 1996). The effects of

chronic ozone pollution on other species are not yet known.

There are resultant biological effects of nutrient deposition on aquatic and terrestrial ecosystems, and this enrichment can have considerable effects on sensitive organisms or communities (e.g., lichens and phytoplankton)—even at very low levels of atmospheric deposition (Fenn et al. 2003).

High-elevation aquatic ecosystems in the Sierra Nevada are particularly sensitive to change from atmospheric deposition because the waters are oligotrophic and have a low buffering capacity. In Yosemite, correlations between higher nitrate concentrations in sensitive surface waters and areas of higher nitrogen deposition have been observed (D. Clow, Hydrologist, USGS, pers. comm.). In contrast, decreased exports in dissolved nitrogen were observed in Emerald Lake in Sequoia National Park. The decrease was attributed to increased phosphorus inputs that caused a switch from a lake dominated by phosphorus limitation to one dominated by nitrogen limitation. Sickman et al. (2003) described two trends in nitrate concentrations in Emerald Lake. During snowmelt, nitrate pulses (i.e., peak values during April) were related to snowpack depth—the deeper the snowpack the greater the nitrate pulse. There is little variation in precipitation concentration, therefore, the quantity of precipitation (i.e. snowpack depth) is the determining factor.

The second pattern, and the one most relevant to phytoplankton, is a decline in summer/autumn lake nitrate concentrations to zero between the 1980s and 1990s. This late season decline occurred despite the fact that N deposition did not decrease. Instead, increased phosphorus loading allowed the phytoplankton to fully utilize nitrate during the summer/autumn seasons, driving them into a N-limited trophic state. The cause of increased phosphorus loading is unknown, but inputs from atmospheric deposition, soils, and sediments are likely reasons and the subject of ongoing research.

Mid-elevation, mixed-conifer watersheds in Sequoia's Giant Forest have shown net retention of nitrogen,

with stream concentrations often below detection limits (Williams and Melack 1997a). Giant sequoia forests are particularly effective at immobilizing nitrogen and reducing leaching losses; they may be adapted to even more nutrient poor environments than other coniferous ecosystems (Stohlgren 1988).

The consequences of increased nitrogen deposition and retention on terrestrial plant communities in the Sierra Nevada are unknown, but greater foliar biomass production, resulting in enhanced litter accumulation on the forest floor (fuel) and in aboveground biomass (stand densification), may increase the risk of severe fire damage (Fenn et al. 2003). Nitrogen pollutants are likely to be important in causing changes in lichen communities—e.g., shifts to nitrophilous species or changes in abundance (Nash and Sigal 1999). Increased levels of soil nitrogen caused by atmospheric nitrogen deposition can increase the dominance of non-native invasive plants and decrease diversity of native plant communities (Vitousek and Howarth 1991, Vitousek et al. 1997). Enhanced growth of invasive species from increased nitrogen has been observed in coastal sage scrub of Southern California, and is implicated in exacerbating invasion of Mediterranean nonnative grasses (Allen et al. 1988). Changes in the alpine plant community of the Rocky Mountains from nitrogen deposition have been observed (Bowman 2000).

With continued urbanization of California's Central Valley, with increasing livestock operations, and with the possibility of transpacific N transport from Asia, it is probable that N deposition and its ecosystem effects in the High Sierra will increase in the next several decades (Fenn et al. 2003).

High elevation lakes and streams in the parks are very dilute and sensitive to change from atmospheric deposition of nutrients, toxic substances, and acids. While chronic acidification is currently not a problem, episodic depression of acid-neutralizing capacity occurs during snowmelt (Melack and Sickman 1995b, Melack et al. 1998b) and episodic acidification occurs during

what are known as “dirty rainstorms”, i.e., rainstorms of summer and early fall (Stohlgren and Parsons 1987). If acid deposition increases—which is likely due to rapid population growth in the San Joaquin Valley—episodic acidification will become more frequent and may alter aquatic communities. Recent research suggests Sierra Nevada waters may be fairly resilient and able to buffer current and potentially increased inputs (Leydecker et al. 1999). The actual threat to water quality posed by episodic acidification, however, is unknown.

Sequoia, Kings Canyon, and Yosemite are downwind of one of the most productive agricultural areas in the world, the San Joaquin Valley. Every year, millions of pounds of pesticides (net weight of active ingredient) are applied to crops—9,872,707 pounds in 2003 alone (Pesticide Use Database, managed by California Department of Pesticide Regulation, <http://www.cdpr.ca.gov/>). Pesticides volatilize, i.e., become suspended in the atmosphere as particulate matter (atmospheric contaminants), then drift into the parks on prevailing winds. Organophosphates have been found in precipitation up to an elevation of 1,920 meters in Sequoia (Zabik and Seiber 1993). Some synthetic chemicals are endocrine disruptors (hormonal mimics) in concentrations of parts per trillion, potentially leading to altered wildlife reproductive capacity, longevity, behavior, and cancer and mutations (Colburn et al. 1996). Synthetic chemical drift also may play a role in decline of mountain yellow-legged frogs and other amphibians in the Sierra Nevada (Sparling et al. 2001, Davidson and Shaffer 2002). While there is correlation between ecosystem effects and synthetic chemical presence, the mechanism for specific pesticide effects has not been established.

Habitat Fragmentation and Human Use

Human use and park fragmentation typically results in: habitat loss, altered fire regime, diversion of water, disruption to wildlife, increases in non-native species invasions and may degrade wilderness values (e.g., dark night sky, natural soundscape).

Sierra Nevada parks have the potential to become functional biological islands due to future human population growth and increases in amounts and types of development on adjacent lands. Population growth for the Sierra bioregion is forecasted to increase by over 50 percent in the next 20 years, from 717,400 in 1990 to 1,110,200 by 2020 (Fire and Resource Assessment Program 1997). This will pose increasing challenges for preserving park ecosystems and biodiversity. Several species already have disappeared from the parks (e.g., grizzly bear, California Condor, California red-legged frog), and others survive in greatly reduced numbers (e.g., mountain yellow-legged frog, Yosemite Toad, Western pond turtle, Willow Flycatcher) (NPSpecies Database <https://science1.nature.nps.gov/npspecies/>). These losses are partly due to habitat loss on adjacent lands, with park habitat being insufficient to support local populations over the long term (Graber 1996). This problem is particularly serious for foothill species, including seasonally resident species, because most land adjacent to undisturbed foothill habitat is primarily privately owned and subject to development, grazing, agriculture, water diversions, altered fire regime, and non-native invasive species (including freeranging pets and feral animals).

Coniferous forests on lands adjacent to park boundaries are mostly within national forests, where forest ecosystems have been altered by timber harvest, grazing, water diversions, non-native invasive species, and altered fire regimes. Declines of forest mesocarnivores (e.g., wolverine, fisher, red fox), bats, and owl species are attributed to forest structure changes in the region (DeSante 1995, Graber 1996).

Livestock grazing on other non-park public land east of the Sierra Nevada crest has prevented re-establishment of healthy metapopulations of Sierra Nevada bighorn sheep (*Ovis canadensis* ssp. *nova*) within the parks, leading to their endangerment (Wehausen 2003).

Animals that routinely travel outside park boundaries (e.g., mule deer, black

Table F–3. Listing of stressors and documented resources management issues, by park.

| STRESSORS AND RESOURCE ISSUES | DEVILS POSTPILE | SEQUOIA & KINGS CANYON | YOSEMITE |
|---|-----------------|------------------------|----------|
| Air and Climate | | | |
| Climate change | • | • | • |
| Precipitation change & spring runoff pattern | • | • | • |
| Elevated ozone | | • | • |
| Particulate matter | | • | • |
| Smoke management | | • | • |
| Visibility Impairment | | • | • |
| Nitrogen deposition | | • | • |
| Persistent organic pollutants | | • | • |
| Water | | | |
| Recreational use (litter, human waste, stock) | • | • | • |
| Reduction in snowpack, icefields, glaciers | • | • | • |
| Change in snowmelt timing | • | • | • |
| Road runoff | • | • | • |
| Riverbank compaction & erosion | • | • | • |
| Atmospheric contaminants | | • | • |
| Elevated nutrients | | • | • |
| Diversions and dams | | • | • |
| Altered fire regimes and resultant effects on flow and chemistry | | • | • |
| Groundwater withdrawal | | • | • |
| Water diversion | | • | • |
| Arsenic from volcanic sources--potential threat to drinking water | • | | |
| Better hydrology baseline data needed | • | | |
| Old mines | | • | |
| Biologic | | | |
| Effects of climbing on large granite faces (hardware litter, rock face damage) | | | • |
| Sedimentation and erosion after severe fire | • | • | • |
| Development in rockfall zones | | | • |
| Erosion of riverbank soils due to visitor use | • | | • |
| Soil compaction due to visitor use | | • | • |
| Effects of rockclimbing | • | • | • |
| Roads across braided stream channels | | | • |
| Effects of contaminants originating from waste accumulation sites (e.g., old dumps) | | | • |
| Loss of glacial polish on postpile columns (trailing, erosion) | • | | |

bear, and band-tailed pigeon) thereby become part of hunted populations. Such management activities outside parks are likely to affect age structure and abundance of species within park boundaries. Non-hunted park populations are a likely reservoir for hunted and less dense populations outside the parks.

Concomitant with population growth are changes in wilderness values such as dark night sky and the natural soundscape. Dark night sky benefits many living things, and light pollution is rapidly eroding the unspoiled view of stars. Natural sounds (e.g., morning bird chorus) are integral to the park experience for visitors and essential to the health of ecosystems. Increases in anthropogenic sound such as from airline over-flights can disrupt wildlife behavior.

Additional Resources Management Issues in SIEN Parks

Network park managers and researchers, using best professional judgment, have identified a suite of resources management issues and concerns, in addition to the five systemic stressors. We identify both broad scale and localized stressors and resource issues for individual Sierra Nevada Network parks, in Table F–3.

Overview Model: Landscape Exchange

A landscape can be thought of as an “open” system that exchanges energy, materials, and organisms with its surroundings. In this context, broad-scale processes constrain these exchanges among landscapes. For example, our regional climate is considered a constraint on the Sierra Nevada landscape. The various ecosystems in a given landscape are linked by the movement of plants and animals, air, water, energy, and biogeochemical cycles (Turner 1989). Park “boundaries” are mostly arbitrary demarcations with respect to atmospheric, hydrologic, and other ecosystem processes.

The major interactions between park landscapes, with the larger surrounding Sierra Nevada ecoregion, are illustrated

in Figure F- 4. Many of the portrayed exchanges are common to all Sierra Nevada landscapes, regardless of shape, size, or locality. Some external inputs into parks are little-influenced by the parks themselves—these include meteorological inputs (e.g., precipitation, solar radiation) and airborne pollutants (e.g., nitrogen, persistent organic pollutants). As depicted, park landscapes exchange energy, materials, organisms, and processes with the adjacent landscapes and larger eco-region (within which it is embedded).

For example, birds and other animals freely cross the boundary between park and nonpark habitats. Fire can propagate into or out of a park unit. Non-native invasive species present outside park boundaries can be transported into a park area by wind, animals, or human activities. River flows can originate within a park watershed, passing through its boundary on its way to lower elevations, or may only flow through a park and therefore not encompass the uppermost reach of the watershed (e.g., San Joaquin River through Devils Postpile). Park areas of smaller extent, such as Devils Postpile, may be more profoundly influenced by their surroundings than those of larger extent; larger parks may be better able to buffer disturbances and other outside influences.

Implications of these exchanges (of materials, organisms, etc.) on park resources need to be explored and related to management concerns. Although we often cannot control what enters a park, we can monitor its effects, communicate that information widely, and mitigate, to some extent, through thoughtful management.

Table F–3. Cont'd.

| STRESSORS AND RESOURCE ISSUES | DEVILS POSTPILE | SEQUOIA & KINGS CANYON | YOSEMITE |
|---|-----------------|------------------------|----------|
| Biologic (cont'd) | | | |
| Erosion of fragile volcanic soils from social trailing | • | | |
| Volcanic and earthquake activity (regional) | • | | |
| Erosion and undercutting along riverbanks—visitor use | • | | • |
| Roads in rockfall zones | | • | • |
| Damage to caves (e.g., visitation, vandalism) | • | | • |
| Ecosystem Processes | | | |
| Altered fire regimes | • | • | • |
| Altered biogeochemical cycles (elevated PO ₄ , NO _x , NH ₄) | • | • | • |
| Wilderness | | | |
| Preserving natural soundscape (e.g., overflight issues) | • | • | • |
| Preservation of dark night sky (from light intrusion) | • | • | • |
| Snowmobile trespass | • | | • |
| Day use | • | • | • |
| Habitat Fragmentation, Loss, and Land-use Change (e.g. development) | | | |
| Development, logging, grazing outside boundaries | • | • | • |
| Roads and developed areas inside boundaries | | • | • |
| Logging, grazing, ski resort, and other development outside boundaries | • | | |
| Potential groundwater pumping by Mammoth Lakes at San Joaquin Ridge-reduced flows | • | | |
| Dams—impediment to fish migration | | | • |

Sources: Park vital signs workshop reports ((Mutch and Lineback 2001, Mutch 2002, Mutch and Thompson 2003); Evaluation of Existing Water Resources Information in Sierra Nevada Network for the Vital Signs Water Quality Monitoring Plan (Appendix D); water resources scoping meeting summary (Heard and Mutch 2003); Sequoia and Kings Canyon Resources Management Plan (Sequoia And Kings Canyon National Parks 1999b); Yosemite National Park Resources Management Briefing Package (National Park Service 2003b); Sierra Nevada Ecosystem Project Report (SNEP 1996); and park staff.

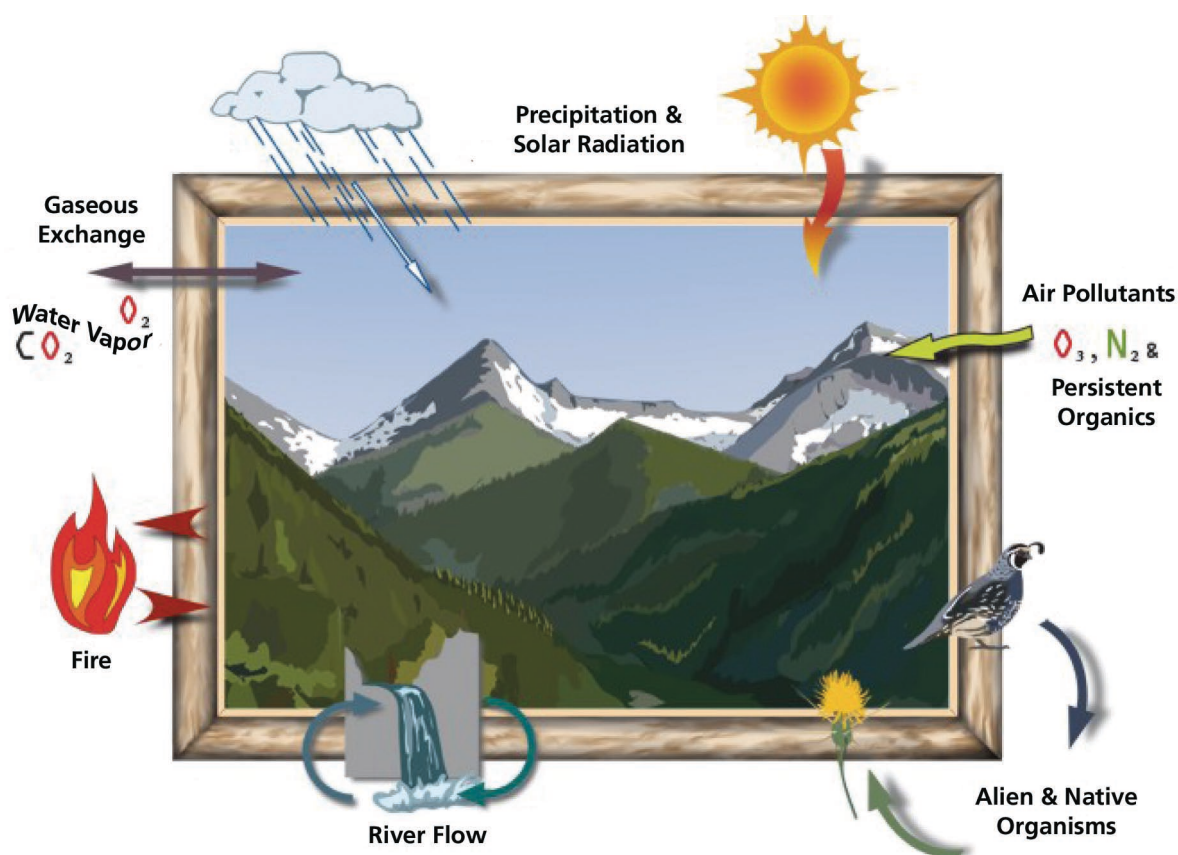


Figure F-4. Major inputs and exchange of energy, materials, organisms, and processes for a given Sierra Nevada parkland (landscape) and its physical surroundings. Illustration by Justin Hofman (NPS intern).

Overview Model: Landscape Dynamics

Introduction

There are a variety of major factors threatening the integrity of Sierra Nevada ecosystems. As mentioned, science has identified rapid anthropogenic driven climate change (rapid anthropogenic), altered fire regimes, invasive species, pollution, and habitat fragmentation as the five primary threats to Sierran systems (SNEP 1996). With a rapidly expanding human population, and a steeply rising projection in the state's population size, these threats are likely to increase in scope and severity. In particular, the Sierra Nevada foothills are projected to be heavily impacted by future development.

Climate change is predicted to play an increasingly important and serious role in California, posing a significant threat to the existence and persistence of native ecosystems and species (California Energy Commission 2003, Hayhoe et al. 2004).

Decades of fire suppression and predicted climate shifts are likely to bring dramatically altered fire dynamics to the Sierra Nevada.

We have selected landscape dynamics as a high-priority monitoring protocol for development because many landscape elements and processes are sensitive to the stressors identified above (see Figure F- 5) and associated discussion for additional detail on these threats and stressors). Another reason we are interested in monitoring landscape dynamics is because remote-sensing technology provides a cost-effective means of detecting and assessing change in our large Wilderness parks, where spatially-extensive on-the-ground monitoring will not be feasible for all vital signs. Remote-sensing data when used with other ground-based monitoring data and modeling can help establish relationships among major drivers, stressors, and landscape patterns and provide early warning of changes that may at times be mitigated

by management actions.

The landscape model (Figure F-5) highlights core drivers, system components and functions, and stressors that interact to influence landscape dynamics and patterns. We include definitions of important landscape terms below.

Landscape Definitions

Ecosystem: a dynamic complex of plant, animal, and micro-organism communities and their non-living environment interacting as a functional unit (Convention on Biological Diversity 2005)

Landscape: a mosaic where a cluster of local ecosystems is repeated in similar form over a kilometers-wide area (Forman 1997)

Landscape element: each of the relatively homogeneous units, or spatial elements recognized at the scale of a landscape mosaic. This refers to each patch, corridor, and area of matrix in the landscape (Forman 1997)

Landscape mosaic: a geographic group of site-level ecosystems (Bailey 1998)

Patch: a relatively homogeneous nonlinear area that differs from its surroundings (Forman 1997)

Mosaic: a pattern of patches, corridors, and matrices, each composed of small similar aggregated objects (Forman 1997)

Drivers, System Components, Functions

Climate and atmosphere, geology and topography, and various processes of change are core drivers that influence the Sierra Nevada landscape, and interact with each other to influence patterns of vegetation, animal distributions, water dynamics, and soil characteristics.

Climate

Climatic forces are a major driver of Sierra Nevada ecosystems. Strong climatic gradients occur with changing elevation from west to east. Low to

mid-elevations have a Mediterranean climate, characterized by hot, dry summers and cool, wet winters. Higher elevations are dominated by a micro-thermal (or Boreal) climate. As a result, a steep temperature gradient parallels the elevation gradient as one climbs from the hot lowlands to the alpine crest (Stephenson 1988). The west slope of the Sierra receives between 50 and 200 cm of rainfall each year, depending on elevation. Above 2,100 m on the western slope, about 50% of precipitation falls as snow (Stephenson 1988), creating a significant snowpack in the montane and subalpine elevations. East of the crest, the mountains create a rain shadow with significantly less moisture falling throughout the season. Long-term changes in past climate regimes have resulted in shifts in fire regimes and vegetation distribution.

Geology & Topography

The Sierra Nevada range has been formed and shaped by a variety of geologic events:

- Uplift and tilting to the west from a magma intrusion approximately 215–70 million years ago, giving the range its asymmetric geometry (gentle west slope, steep east escarpment)
- Erosion and incision from streams, resulting in deep canyons
- Volcanic activity at approximately 100 thousand years ago on the eastern flank of the Sierra Nevada that sent a lava flow into a valley, now designated Devils Postpile National Monument, which cooled uniformly, contracted, and fractured into hexagonal columns for which the monument is named
- Several glacial periods in the Sierra Nevada, beginning at approximately 1 million years ago and continuing until approximately 10 thousand years ago, which scoured and eroded the landscape and resulted in landforms that include U-shaped canyons, jagged peaks, rounded domes, waterfalls, moraines, and lakes & ponds

Many of these processes continue to gradually change the terrain of the Sierra Nevada today.

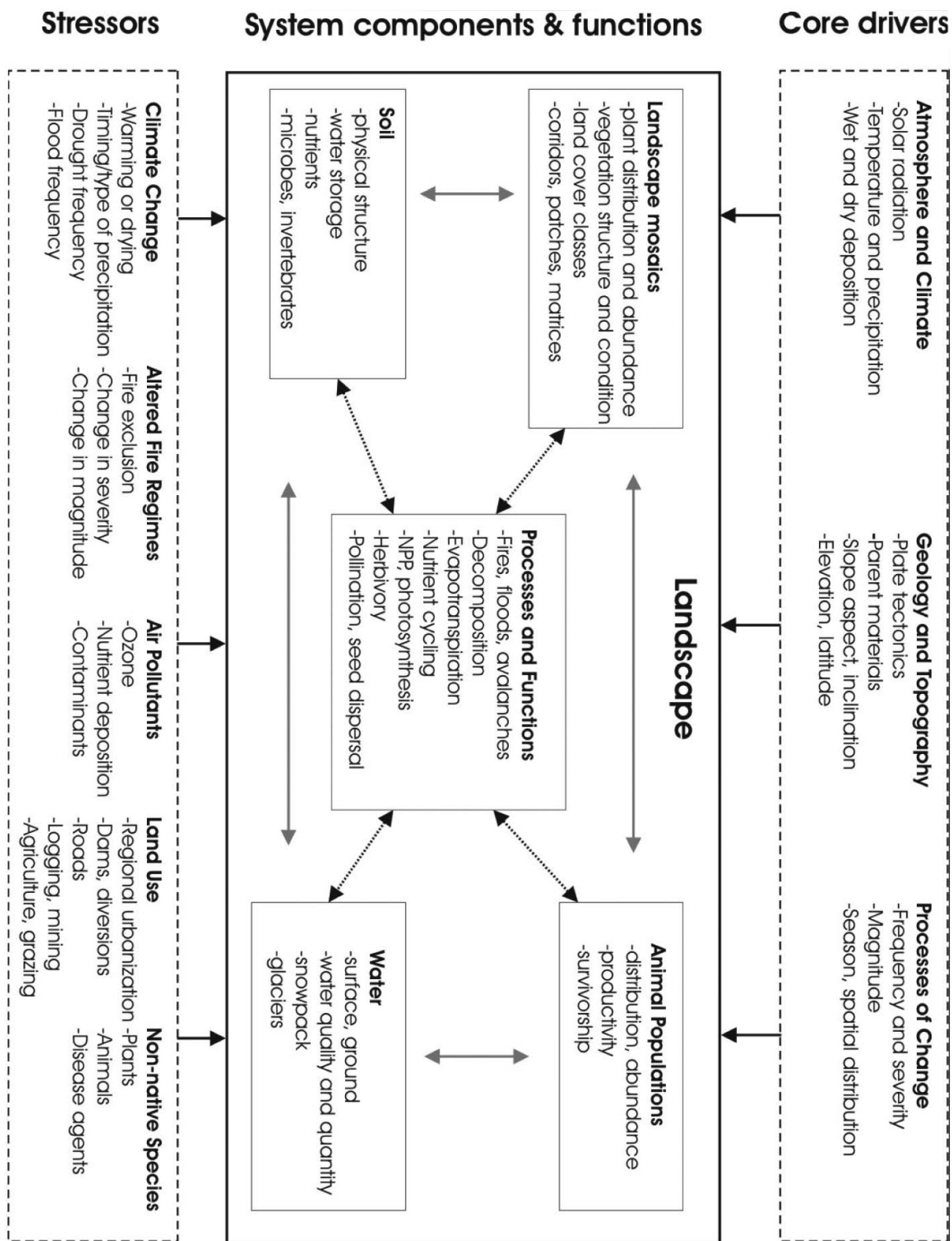


Figure F-5. Landscape dynamics model for the Sierra Nevada.

Massive granite outcrops dominate the range. The granite formed deep within the Earth when molten rock solidified, and later was exposed following erosion of overlying rocks. Layered metamorphic rocks in the western foothills and along the eastern margin near the Sierra crest are remnants of ancient sedimentary and volcanic rocks. Most of these rocks were long ago eroded away to expose the granitic core of the range, and only small isolated remnants remain.

Topography of the Sierra Nevada interacts with climate to strongly influence the distribution of plants and animals. Temperature, precipitation, and moisture available to plants vary with changes in elevation, latitude, and slope inclination. The length and elevation range of the Sierra Nevada, combined with its topographic diversity result in large gradients in temperature and precipitation and high diversity of plants and animals.

Fire

While many processes of change have formed and shaped the Sierra Nevada landscape, the current process that has the most pronounced effect on plant community structure and composition is fire. Characteristics and influences of fire regimes are discussed in a later section, associated with both the “fire regimes” and “forest system” descriptive models. Other processes of change that periodically are important in limited portions of Sierra Nevada landscapes include floods, avalanches, rock slides, and hillslope erosion.

Some of these processes are linked to particular weather events (such as large amounts of rain on snowpack), topographic or geologic characteristics (steep rock walls or slopes, tectonic activity), or severe fire events. Processes of change have varying effects on landscape mosaics, and these effects are related to their frequency and severity, magnitude, and seasonal and spatial distribution.

Water & Soil

Additional landscape components or elements that we emphasize in our model include water, soil, landscape

mosaics, and animal populations. These components interact directly through exchange of materials or provision of habitat as represented by the solid grey arrows linking landscape element boxes. Much of the interaction and exchange among landscape elements occurs via processes and functions shown in the middle box of the model. For example, key processes such as decomposition, fire, and herbivory result in exchanges of nutrients from one “box” to another. As a result of fire, organic matter tied up in fuel and vegetation can be deposited as nutrients in soil.

Water in a landscape context is characterized by drainage networks across an elevation gradient. Drainage networks provide surface pathways for water flow across the landscape, and the distribution of species is strongly influenced by the spatial and temporal patterns of water availability. Water quantity in the Sierra Nevada and the region at large is strongly influenced by the winter snowpack, which serves as a reservoir that gradually releases water through snowmelt and runoff. Atmospheric deposition, surface runoff, sedimentation, and processes such as fire, erosion, and flooding all influence water quality. Soil is a source of nutrients that are transported into streams, rivers, and lakes, and it also provides storage for water making it available for plant uptake.

Soil provides physical structure and habitat for plants as well as other organisms (microbes, fungi, invertebrates, vertebrates). Soil is the medium through which nutrients and water are made available to most plants, and provides varying levels of water storage capacity. Soil formation depends upon parent materials, slope, exposure, hydrology, organic matter content, and surface vegetation, among other factors. The soils of the large parks are primarily granitic in origin. Depths vary from several feet in limited low elevation areas on the western slope, to a very thin or nonexistent soil mantle at higher elevations which resulted from glacial scouring in the alpine and subalpine areas. Soil depth is an important factor in determining water availability to plants, and thus plays a role in the distribution

of vegetation (see “Forest System Model”).

Devils Postpile National Monument is predominantly covered with pumice, indicating postglacial volcanic activity in the Mono Lake—Mono Basin area. This pumice plays an important role in the area’s phytogeography and vegetation development.

On slopes underlain by basalt and andesite, where the water table is low and percolation is high, a sparse conifer forest normally exists. Here, pines and firs contribute little organic matter towards extensive soil formation. The soils remain barren with a paucity of litter and insufficient moisture to enhance soil-formation. It is common, on steeper slopes, to see bare rock and few plants. The plants often creep downhill with the soil, further inhibiting soil development (National Park Service 1982). These dry, unstable soils result in slow recovery of vegetation after human disturbance and more prolonged re-vegetation periods in areas that have burned.

Landscape Mosaics

Landscape mosaics are primarily influenced by abiotic constraints (elevation, soil, microclimate, topography), biotic processes (demography, competition, dispersal) and disturbance regimes (Urban et al. 2000). Landscape mosaics consist of contiguous patches of different types (Figure F- 6), which are areas that are relatively homogeneous in character (e.g., wetlands, high-elevation lakes). Vegetation forms a primary and dynamic component of landscape mosaics, and its relationship to climate and fire in the Sierra Nevada as well as its importance to wildlife habitat make it an important landscape component to monitor.

Other important elements of landscape mosaics include corridors (connectors or barriers). These are primarily linear features in the landscape. Barriers prevent flow across the landscape. The flows could be physical, such as water, or biological, such as animal migration. In contrast, connectors provide paths that promote flow through the landscape. Some landscape features, such as a river

or a road, may be both a barrier and a connector depending on the process or organism of interest. These corridors are important to animal populations as they either link patches of habitat (as streams link lakes for amphibians), or they fragment habitat (as trails fragment invertebrate habitat in wetlands).

Animals

The distribution and abundance of animal populations are tied closely to the pattern of landscape mosaics and the varieties of wildlife habitat that they provide. The mobility of many animal populations makes them sensitive to changes that occur in landscapes both within and outside of park boundaries. Animals can form links among different landscape mosaics (lakes, wetlands, forests) by spending parts of their life cycles in different environments, or by moving among various environments for foraging and hunting. Animal productivity and survivorship are sensitive to weather patterns, fire regimes, and other factors that influence habitat availability and quality. Animals affect vegetation dynamics through herbivory, pollination, and seed dispersal. They influence nutrient cycling in both aquatic and terrestrial systems. Animals contribute substantially to the biodiversity of the Sierra Nevada landscape, and they are major components of complex food webs.

Stressors

Ecosystem stressors are detailed within our stressor model (supra), and in Chapter 1 of our Vital Signs Monitoring Plan. We review their effects, related to landscape, briefly below.

As detailed supra, five systemic stressors pose the greatest threat to Sierra Nevada Network parks and landscapes:

- Climate change (rapid, anthropogenic)
- Altered fire regimes
- Non-native invasive species
- Air pollution
- Habitat fragmentation and human use

Climatic change may have the greatest potential to affect ecosystems at the

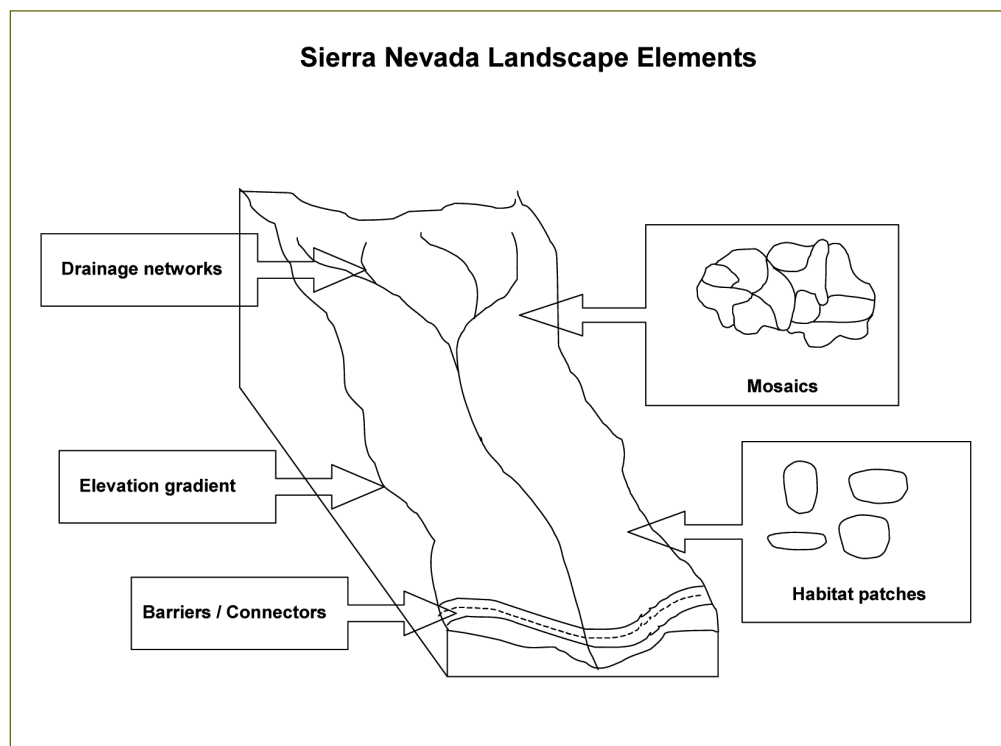


Figure F-6. The structure of a landscape is defined by the spatial arrangement of the components within that landscape. These spatial components include such elements as drainage networks, patches, mosaics, elevation gradients, barriers, and connectors.

landscape scale in part because of its pervasiveness and extent across ecosystems as well as synergistic effects with other stressors.

Recent simulations of climate change models suggest that by the years 2050 to 2100, average annual temperature in the Sierra Nevada could increase by as much as 3.8° C (6.8° F) (Snyder et al. 2002). Even more modest temperature increases (2.5° C, 4.5° F) would significantly alter precipitation, snow pack, surface water dynamics (e.g., flow), and hydrologic processes in the Sierra Nevada. The most pronounced changes would probably be earlier snowmelt runoff and reduced summer base flows and soil moisture (IPCC 2007), a lower snowpack volume at mid-elevations (Knowles and Cayan 2001), and increased winter and spring flooding (Dettinger et al. 2004).

Other anticipated effects from warming temperatures include potential shifts in distributions of plants and animals (especially those with narrow niches or at the edges of their ranges), changes in phenological events (nesting, timing

of bloom), and exacerbation of other systemic stressors—altered fire regimes, air pollution, and nonnative plant invasions.

Climate change and associated predicted changes in fire extent, severity, and occurrence are expected to be the primary drivers of landscape change in the Sierra Nevada in the foreseeable future. The altered fire regimes that have resulted from fire exclusion are currently considered one of the most important stressors on our natural systems.

Therefore, it is imperative that we document and understand how climate change will affect fire regimes which will in turn to help interpret changes in plant community composition, structure and function; water chemistry and dynamics; and animal populations' abundance and distribution.

We know from historic photos and other research on vegetation change and fire history that, over the past 150 years, there have been significant changes in landscape mosaics (patterns of vegetation) in the Sierra Nevada. Changes in these landscape mosaics

can be readily observed in repeat photographs (Figure F-7). Sierra Nevada research on vegetation change (Vankat 1970, Vankat and Major 1978, Parsons and DeBenedetti 1979, Roy and Vankat 1999) and fire history (Kilgore and Taylor 1979, Swetnam et al. 1992, Swetnam 1993, Caprio and Swetnam 1995) has demonstrated strong links between vegetation structure and composition, fire, and climate.

Air pollution (ozone, deposition of nutrients, pesticides from agricultural areas) threatens Sierra Nevada ecosystems. Research suggests chronic ozone pollution can lead to shifts in forest structure and composition (Miller 1973). Since then, injury has been well documented in remote pine forests of southern California (Arbaugh et al. 1998; Bytnerowicz 1996; Grulke 1998; Miller et al. 1996), throughout the Sierra Nevada (Arbaugh et al. 1998; Duriscoe 1987b; Duriscoe 1990; Pronos and Vogler 1981) and in other remote forested areas throughout the US downwind of sources. While ozone pollution in California's urban areas has declined in general over the last 20 years, ozone pollution in remote natural areas has increased (CARB 1999). In 1999 the National Park Service ranked Sequoia National Park among the "worst ozone polluted national parks" in the country (National Park Service 1999). If current ozone concentrations remain relatively constant or increase, they may affect the genetic composition of pine and sequoia seedling populations, and contribute to increased susceptibility to fatal insect attacks, death rates, and decreased recruitment (Miller 1973, Ferrell 1996, Miller 1996). Vegetation condition deterioration may occur in the form of foliage damage and dieback from ozone pollution, and shifts in aquatic and terrestrial community composition and function may result from nutrient and pesticide deposition.

Large portions of the three large Sierra Nevada parks (Kings Canyon, Sequoia, and Yosemite) are buffered to some extent from the effects of habitat fragmentation and land-use change that occur in the Central Valley of California to the west of the parks, in the Sierra

Nevada foothills, and on Sierra Nevada national forest lands. Nonetheless, edges of parks bordering these lands, as well as areas/corridors extending into parks, are affected by non-native species invasions, effects of urbanization, agriculture, and deforestation (such as reduced wildlife habitat outside parks and loss of connections among habitats), deterioration of air quality, and deterioration of natural soundscapes and dark night skies. Other forms of land use change include dams and diversions, and within SIEN parks, Hetch-Hetchy Dam on the Tuolumne River is the largest scale example of water impoundment and fragmentation of aquatic habitat.

We selected vital signs to monitor at the landscape scale that we believe will be sensitive indicators of change due to ecosystem stressors.

Vital Signs

There are two primary justifications for wanting to monitor predicted change in landscape dynamics over time:

1. To document the change where and when it occurs. This information can then be applied to direct managers to areas of heightened concern. Remote sensing provides techniques and data to allow for the preparation of scientific responses to environmental change across large landscapes.
2. To use data to build models of predicted future landscape mosaic patterns. This will allow managers to prepare for and then manage for ecosystem changes that are likely to affect processes, systems, and species.

Justification and details (e.g., vital signs, monitoring questions, objectives) for all monitoring protocols are found in Appendix H "Protocol Development Summaries."

Our landscape workgroup has initially selected four vital signs to be monitored as part of our Landscape Dynamics Monitoring Protocol (under development).

Landscape mosaics

Land cover and land-use change

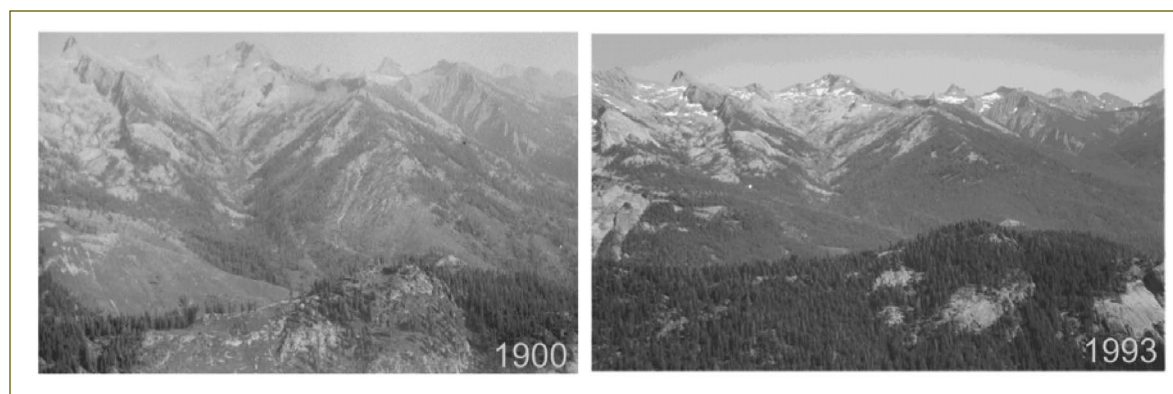


Figure F-7. Repeat photos of Middle Fork of the Kaweah River, Sequoia National Park. Evident in these photos is the change from shrub land to conifer forest over large areas—likely related to a decrease in fire frequency (1900 photo—George Smith, 1993 photo—Nate Stephenson).

are key components of a long-term monitoring program.

Quantifying the occurrence of land cover/use classes within a particular area, over multiple time periods, allows for detection of change in relative occurrence of natural, agricultural, and urban cover types, and provides an index for potential direct (e.g., decreased functional ecosystem size through loss of habitat area, elimination of unique habitats) and indirect (e.g. edge effects, altered ecological flows across landscape, increased human disturbance) ecological impacts of urbanization on park resources (Hansen and Gryskiewicz 2003). Land cover/use characterization captures changes related to urbanization and logging—equally relevant to all park landscapes and ecosystems, but particularly relevant to areas along park edges bordering private and other land management agency lands (e.g., USDA Forest Service, BLM).

Fire regimes

Attributes of pre-Euro-american fire regimes can provide vital reference information for understanding changes in ecosystems over the last 150 years and in developing goals for the restoration of fire. The concept of a fire regime allows us to view fire as a multifaceted variable rather than a single event within an ecosystem (Whelan 1995). Thus, areas can be classified as having a certain type of regime that summarizes the characteristics of fires, within some range of variability, and having both spatial and temporal attributes. Fire

regime characteristics vary through time and across the landscape in response to climatic variation, number of lightning ignitions, topography, vegetation, specific historic events and human cultural practices (SNEP 1996).

For more information on fire regimes, see “Stressor Model,” and “Fire Regime Model.”

Snowpack

Snow is the dominant environmental factor in mountainous regions for more than half of the year (Mote et al. 2005). Sierra Nevada snowpack acts as a temporary reservoir, storing water until the spring snowmelt. Recent modeling work predicts that the average temperature in California will increase 2.1°C (3.8 °F) by 2090, resulting in a 43% reduction to the April snowpack in the southern Sierra Nevada (measured as snow water equivalent) (Knowles and Cayan 2001, 2002, Mote et al. 2005). A trend in the Sierra Nevada, towards smaller ratios of ‘winter-total snowfall water equivalent’ to ‘winter-total precipitation’, during the period 1949–2004, has already been documented (Knowles et al. 2006). If warming trends in our region continue, as projected in response to increasing greenhouse gas concentrations (IPCC 2007), the snowfall fraction of precipitation is likely to continue to decline (Knowles et al. 2006). Monitoring of snowpack at the landscape scale provides information directly related to changing climate and relevant to the water supply of the region—both have high ecological and

economic value.

For detailed information on snowpack, see Stressor Model, and Appendix B, "Parks."

Phenology

Human-influenced temperature patterns are significantly associated with discernible changes in plant and animal (invertebrate, bird, amphibian, tree, shrub) phenological traits (Root et al. 2005). Our objective is to determine how vegetation types are responding to changes in climate and other disturbances. A national phenological monitoring network has been initiated, and recommendations on different approaches to monitoring phenological change in parks and other areas are being developed, see (<http://www.uwm.edu/Dept/Geography/npn/>).

Other

Additional vital signs may be pursued within our landscape dynamics monitoring protocol if resources and adequate methods permit.

Glaciers—spatial extent and distribution

The Sierra Nevada contains approximately 497 alpine glaciers and perennial ice features (Raub et al. 1980). These features provide an opportunity to determine regional responses to warming global temperatures over the past century, i.e., changes in spatial extent and distribution. During the summer of 2003 and 2004, over 52 repeat

images of historic photos were collected from ten glaciers located throughout the Sierra Nevada, providing evidence of glacial shrinking in the past 100+ years (Figure F-8). When a glacier disappears, the water source for that watershed during dry times of the year is reduced, with cascading effects to watershed habitats.

Extent and spatial arrangement of wetlands

Please see wetlands model (below), and Appendix H, "Protocol Development Summaries," for information describing why wetlands are a focal system for vital signs monitoring. Our ability to monitor wetland extent and spatial arrangement will be limited by the resolution of remotely-sensed imagery that we can acquire with available resources.

Fire Regime Attributes

Please see "Fire Regime Model."

II. Models: Systems, Processes, and Populations

Introduction

The following sections present models of the drivers and main focal systems selected for vital signs monitoring in the Sierra Nevada Network. Associated with these focal systems models are details and sub-models that further describe ecosystem processes (e.g., fire regimes, nitrogen deposition, and invasion of non-native plants), effects of drivers on plant and animal community dynamics, population dynamics of focal species,

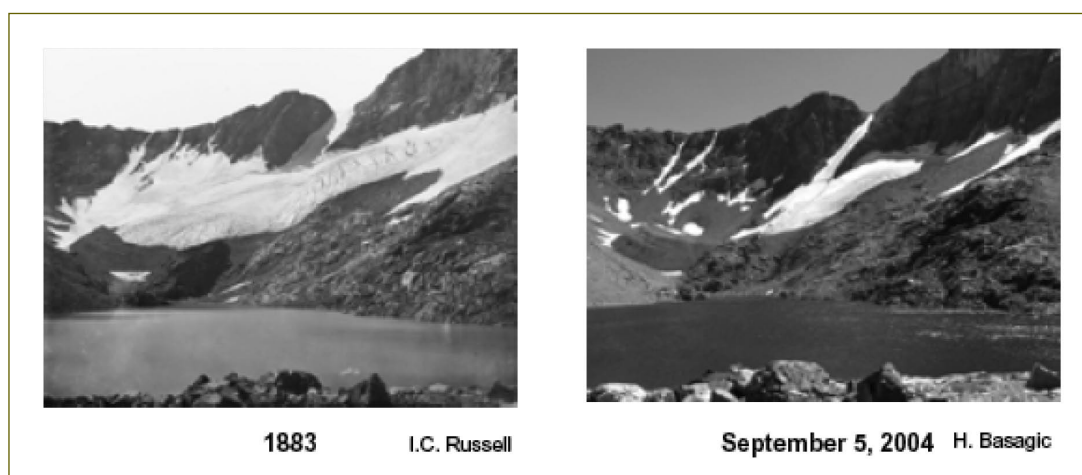


Figure F-8. Repeat photos of Dana Glacier, Yosemite National Park.

and interactions among biotic and physical components in specific systems (e.g., lakes).

We present models that include vital signs selected for monitoring protocol development, or those already monitored by parks within our Network. Linkages among vital signs and models are listed in Table F-4. Where necessary and appropriate, we will develop new—and modify existing—models as part of our monitoring protocols. Our models are at different scales, namely system, process, and population.

Model: Atmospheric System

Our model and text for this section are adapted from Draft Conceptual Ecological Models for the Mojave Network Inventory and Monitoring Program (2006).

Introduction

The atmospheric system drives weather, and the long-term characteristics of weather are described as climate. Stine (1996) generalizes that climate exerts a predominant influence on the following components of the Sierra Nevada landscape:

- Vegetation (type, biomass, distribution)
- Hydrology (size, distribution, fluctuations, and water quality of lakes and streams)
- Soils (stability, nutrient capacity)
- Landforms (rates of formation and loss)
- Fire (location, frequency, seasonal timing, intensity and/or severity)

Drivers, System Components, Functions

Climate & Weather

Climate strongly influences the landscape by determining the flux of both energy (solar radiation) and mass in the form of moisture (rain, snow, water vapor). The atmospheric system conducts most mass and energy, including pollution, to and from the Sierra Nevada. The atmosphere receives solar radiation, which is mediated by reflective aerosols and absorbent trace gases before reaching Earth's surface (Figure F- 9). It also receives water vapor from evaporation at the Earth's surface, and transpiration from plants.

In the zone near the Earth's surface, heat exchange mediates vertical temperature gradient in the atmosphere (Bradley 1985). Although the atmosphere has low heat capacity, it couples with water bodies of much higher heat capacity with the result that energy in the atmosphere is primarily driven by ocean circulation patterns. Interactions between atmosphere and land include evaporation and transpiration, reflected radiation, precipitation, wind, and heat exchange.

Table F–4. Conceptual models (narratives and conceptual diagrams) and the high priority Sierra Nevada Network vital signs that the models include.. Vital signs (bolded) are those currently incorporated into monitoring protocol development (see Appendix H, “Protocol Development Summaries”); other vital signs listed are monitored by Network parks.

| CONCEPTUAL MODEL | VITAL SIGN |
|--|---|
| Sierra Nevada Stressors Landscape Exchange Landscape Dynamics Atmospheric System | Air quality–ozone |
| Sierra Nevada Stressors Landscape Exchange Landscape Dynamics Atmospheric System Nitrogen Deposition | Air quality–atmospheric deposition |
| Atmospheric System | Air quality–particulate matter |
| Atmospheric System Lake System Anuran Populations Rivers & Streams | Air quality–contaminants |
| Atmospheric System | Air quality–visibility |
| Sierra Nevada Stressors Atmospheric System | Weather and climate |
| Sierra Nevada Stressors Landscape Dynamics Atmospheric System | Snowpack |
| Sierra Nevada Stressors Hydrologic System Aquatic System Lake System River & Stream System | Surface water dynamics (hydrology) |
| Sierra Nevada Stressors Hydrologic System Aquatic System Wetland System | Wetland water dynamics (hydrology) |
| Sierra Nevada Stressors Hydrologic System Aquatic System Lake System Anuran Population Rivers & Streams Atmospheric Nitrogen | Water quality–water chemistry |
| Sierra Nevada Stressors Atmospheric Nitrogen Forest System Non-native Invasive Plants Community Invasibility Models | Non-native invasive plants |
| Landscape Dynamics Atmospheric Nitrogen Wetland System | Wetland plant communities (wet meadows and fens) |
| Wetland System Invertebrates | Macroinvertebrates (wet meadows and fens) |
| Landscape Dynamics Forest System | Forest population dynamics |

Table F-4. Continued

| CONCEPTUAL MODEL | VITAL SIGN |
|--|-----------------------------------|
| Aquatic System Lake System Anuran Populations | Amphibians |
| Bird Populations | Birds |
| Sierra Nevada Stressors Landscape Exchange Landscape Dynamics Atmospheric Nitrogen Forest System Fire Regimes | Fire regimes |
| Landscape Dynamics Fire Regimes | Fire effects on plant communities |
| Landscape Dynamics | Landscape mosaics |
| Landscape Dynamics | Phenology |

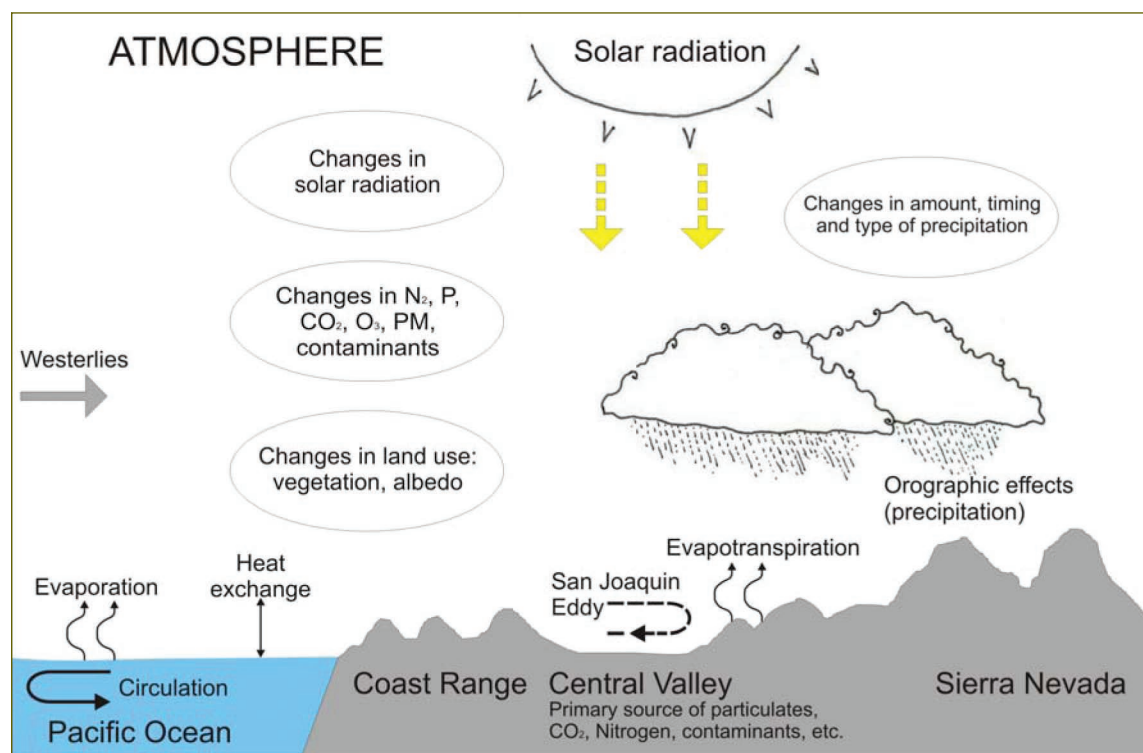


Figure F-9. Atmospheric system conceptual diagram for Sierra Nevada. Principal components, key landscape features, and prominent drivers (in ovals) are depicted.

Strong climatic gradients develop with changing elevation in the Sierra Nevada (low to high elevations, from west to east). Low to mid-elevations have a Mediterranean climate, characterized by hot, dry summers and cool, wet winters. Higher elevations are dominated by a microthermal (or Boreal) climate, characterized by having average temperatures of the coldest month below -3°C (26.6°F). As a result, a steep temperature gradient parallels the elevation and climatic gradient; on average, each 100 m gain in elevation results in a 0.6°C (1.1°F) drop in air temperature. This lapse rate varies locally according to air speed, relative humidity, slope aspect, insolation, and vegetation cover (Stephenson 1988), but the general pattern holds true as one climbs from the hot lowlands to the alpine crest.

As temperature decreases with increasing elevation, so does the moisture-holding capacity of air. The west slope of the Sierra receives between 50 and 200 cm of rainfall each year, depending on elevation. Above 2100 m on the western slope, about 50% of precipitation falls as snow (Stephenson 1988), creating a significant snowpack in the montane and subalpine elevations. By the time winter storms reach the alpine, much of the moisture has been lost from the clouds and the amount of snow accumulating on the ground begins to decline with increasing elevation. East of the crest, the mountains create a rain shadow with significantly less moisture falling throughout the season. Precipitation also increases with latitude, due to the Pacific jet stream position and subtropical high pressure cells. Across elevations and latitudes, nearly 70% of precipitation falls from December through March and only about 4% from June through September (Stephenson 1988). Precipitation increases with latitude, due to Pacific jet stream position and subtropical high pressure cells. Across Sierra Nevada elevations and latitudes, nearly 70% of precipitation falls during December through March, in contrast to only about 4% during June through September (Stephenson 1988).

Climate varies spatially and at annual,

decadal, centennial, and millennial time scales.

Topography and Geology

Topography also directly influences the amount and timing of precipitation, and variability in temperature across large and localized spatial scales. As is evident in Figure F-10, elevation, aspect, and soil depth (e.g., as a result of underlying geology and processes) interact with climate to influence evaporative demand and distribution of Sierra Nevada forest types.

Plants and Animals

Climatic forces are a major driver of Sierra Nevada ecosystems, and thereby strongly influence the distribution of plants and animals.

Numerous paleo-ecological studies have documented vegetation changes over the past many thousands of years in response to changes in climate. Woolfenden (1996) summarizes that during the Quaternary period of the past 2.4 million years, at least six successive major glacial cycles covered the Sierra Nevada with ice caps and mountain glaciers, filled lake basins in the adjacent deserts, and lowered the elevation limits of plant species. These ice ages were interspersed with shorter warm intervals when habitats expanded into northerly latitudes and tree lines gained elevation. Species responded individually to these changes, sometimes assembling into communities with no modern analog (Woolfenden 1996).

Climate affects the distribution of forest types and other plant communities of the Sierra Nevada through its influence on the soil water balance (Stephenson (1988, 1998)). With increasing elevation, temperature decreases (causing decreasing evaporative demand) while precipitation increases. The mixed-conifer zone of the Sierra Nevada is sandwiched between low-elevation sites that are chronically droughty, and high-elevation sites that are too cold to be very productive (Urban et al. 2000). Thus, these systems are quite sensitive to climate variability (Graumlich 1993, Swetnam 1993a). The soil moisture regime interacts strongly with forest

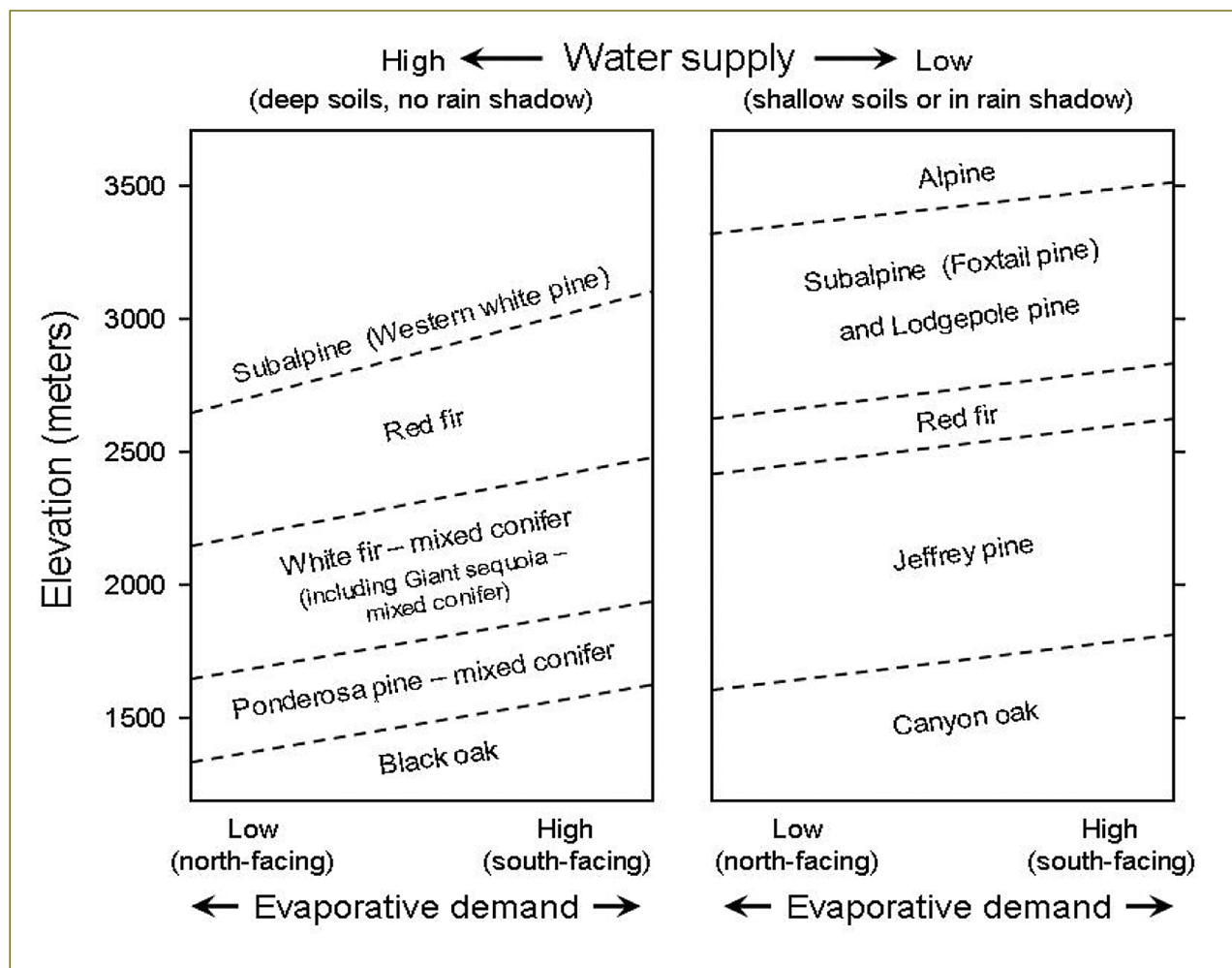


Figure F-10. The approximate distribution of forest types in southern Sierra Nevada relative to elevation, evaporative demand, and water supply.

productivity (via fuel loads) and climate (via fuel moisture), and these systems are especially responsive to fire regime as it interacts with forest dynamics and climate (Miller and Urban 1999c, Miller and Urban 1999a, b).

Stressors

Predicted potential effects of anthropogenic climate change on the Sierra Nevada were discussed in Chapter 1 (Section 1.9.2). These effects will likely be highly synergistic, affecting a host of physical and biological systems in unpredictable ways (CIRMOUNT Committee 2006). Current patterns of vegetation, water dynamics, and animal distribution in the Sierra are determined largely by cumulative effects of past and present climates. Anthropogenic climate change is the stressor predicted to have the most pronounced effects on

Sierra Nevada ecosystems. Some of the expected—or already occurring—changes include:

- Altered fire regimes – larger, more severe fires (Torn and Fried 1992, Miller and Urban 1999c)
- Lower snowpack volume at mid-elevations (Adam 1981, Knowles and Cayan 2001, Knowles et al. 2006); a trend towards smaller ratios of ‘winter-total snowfall water equivalent’ to ‘winter-total precipitation’ (Knowles et al. 2006)
- Increased winter and spring flooding (Dettinger et al. 2004)
- Earlier snowmelt runoff, reduced summer base flows and soil moisture (Dettinger et al. 2004, Dettinger 2005)
- Increased turnover rates in forests (Stephenson and van Mantgem 2005,

Knowles et al. 2006)

- Upward shifts in species or habitats, and losses of species that cannot adjust; potential shrinkage of some habitats (alpine, wetlands) (Patton 2006).

In addition to influencing weather and climate patterns, atmosphere dynamics interact with topography to influence air patterns, affecting the distribution and deposition of pollutants. Ozone, agricultural pesticides, particulate matter, and nitrogen compounds are a few examples of pollutants deposited through dry and wet deposition in Network parks (see Chapter 1, Stressor Model (Figure F-2), and Appendix C, “Air Quality Synthesis” for more detail on pollutants, sources, air flow patterns, and ecosystem effects).

Atmospheric dynamics combine with emissions of air pollutants to influence air quality. The San Joaquin Valley, west of Sierra Nevada parks, is a trap for air pollutants. Pollutants originating in the valley and pollutants from cities along the central California coast are carried in on prevailing winds. Southward-flowing air currents enter California at San Francisco Bay and move southeast, through the valley, until reaching the east-west mountain block at the southern end of the basin. An eddy thereby forms in the vicinity of Visalia and Fresno, just west of the southern Sierra Nevada (see Figure F- 3) (Lin and Jao 1995). Thermal inversions frequently trap air over the valley at night during the summertime. Airborne pollutants are then transported into the mountains when this air rises during the day. As a result, Sequoia and Kings Canyon have some of the worst air quality found in any NPS unit in the country (Cahill et al. 1996). Yosemite and Devils Postpile are also impacted, but to a lesser degree.

Sierra Nevada parks are subjected to the following sulfur-based and nitrogen-based pollutants, elevated levels of ozone, and pesticides:

Sulfur-based pollutants: Fossil fuel combustion, vehicle exhaust, paper manufacturing, and other industry produces SO_2 . Although levels of SO_2 toxic to lichens are found in Los

Angeles and other urban areas, SO_2 occurs in relatively low concentrations in more remote areas in California (Jovan and McCune 2005).

Acid Deposition: Acid deposition is the generic term to include wet and dry deposition of acidic forms of primarily nitrogen and sulfur compounds. Acidic derivatives of sulfur dioxide (SO_2) and nitrogen oxides (NO_x) are the principle acidifying agents. In the Sierra Nevada, air monitoring suggests that sulfuric acid is likely to be less of a problem than nitric acid. Sierra lakes have shown sensitivity to low levels of acid deposition due to thin topsoils, granitic subsurface layers, sparse vegetation, steep slopes, and dry climate. Precipitation in the Sierra Nevada comes during late summer rains and spring snowmelts, delivering acidic pulses of water to lakes and creeks (Stohlgren and Parsons 1987, Melack and Sickman 1995, Melack et al. 1998).

Ozone: Ozone is a photochemical pollutant formed when nitrogen oxides (NO_x) and hydrocarbons react with oxygen and sunlight. Tropospheric ozone (O_3) pollution is widespread in California, occurring in both urban and rural areas, causing injury to both wild and crop plants (Miller 1973, Duriscoe and Stolte 1992, Peterson and Arbaugh 1992, Stolte et al. 1992, Miller 1996), and causing human health problems because it damages lung tissue, reduces lung function, and sensitizes the lungs to other irritants.

Pesticides: Sequoia, Kings Canyon and Yosemite are downwind of one of the most productive agricultural areas in the world, the San Joaquin Valley. Every year, millions of pounds of pesticides (net weight of active ingredient) are applied to crops—9,872,707 pounds in 2003 alone (California Department of Pesticide Regulation, <http://www.cdpr.ca.gov/>); 2 billion pounds of active ingredients were applied in California between 1991 and 2000 (see Appendix C, “Air Quality Synthesis”). Pesticides volatilize or become suspended in the atmosphere as particulates, then drift into the parks on prevailing winds.

Nitrogen: Inputs of fixed nitrogen into ecosystems of the United States

have doubled since 1961 due mainly to agricultural application of nitrogen fertilizers, combustion of fossil fuels, and industry (Howarth et al. 2002). In the Sierra Nevada, too, nitrogen deposition has become a major concern (Fenn et al. 2003). Ammonium nitrate (NH_4NO_3) is a major component of fine particulate matter deposited in Sequoia and Kings Canyon National Parks (see Appendix C, “Air Quality Synthesis”), and is likely active in altering the plant communities (e.g., lichen) in Sierra parks (McCune et al. 2006). In Sequoia National Park, ammonia and ammonium are the dominant N pollutants in summer, indicating strong influence of agricultural emissions (Bytnerowicz et al. 2002).

Because nitrogen deposition is a major concern in Sierra Nevada ecosystems, we include a separate nitrogen conceptual model).

The severity of air pollution may worsen with warmer climate conditions because temperatures create perfect conditions for the production of “smog,” or ground-level ozone. Monitoring of climate, along with various indicators associated with poor air quality in the Sierra Nevada (such as those currently monitored by parks), will be important in understanding current changes in physical processes in aquatic and terrestrial systems, nutrient dynamics, and plant and animal communities. It is an important part of modeling future changes in these systems.

Vital Signs

The Sierra Nevada Network will monitor selected components of weather and climate because: (1) changes in regional climate patterns will cause change in ecosystems, and (2) climate data will be used to explain patterns observed in other vital sign measures.

We will assess current climate monitoring, including identifying data gaps and determining ‘high priority’ sites for both park and individual vital signs monitoring. Assessment will also include: (1) the need for, and feasibility of, adding new stations in the parks, (2) determining the need for added instrumentation for existing sites, (3) making data more available or real-time, and (4) assisting with maintenance

of meteorological stations and sites.

We will also coordinate micro-scale weather monitoring across vital signs, depending on the needs of other work groups—if any of our vital sign protocols include the collection of weather/climate parameters (e.g., air temperature, relative humidity, etc.), then the type of equipment and protocols should be consistent.

Vital signs and (measures) include: weather and climate (precipitation, temperature, wind speed, wind direction, solar radiation, relative humidity, soil moisture, soil temperature), and snowpack (snow depth, snow cover, snow water equivalent, timing of snowmelt).

Sub-Model: Nitrogen Deposition

Introduction

Nitrogen (N) is a limiting nutrient for many terrestrial and aquatic organisms (Vitousek and Howarth 1991).

Resulting biological effects of nitrogen deposition on aquatic and terrestrial ecosystems, and this enrichment can have considerable effects on sensitive organisms or communities (e.g., lichens and phytoplankton)—even at very low levels of atmospheric deposition (Fenn et al. 2003).

Drivers, System Components, Functions

The biogeochemistry of nitrogen is complex, with significant control of its cycling relegated to biotic processes (Delwiche 1970). We include a model illustrating possible linkages among nitrogen deposition, N cycling, carbon allocation, invasive plant species, fire regime, and community composition because of documented increased deposition of nitrogen to Sierra Nevada ecosystems (Figure F–11) (Fenn et al. 2003).



Meteorological station, Sequoia National Park, monitors precipitation and numerous other components of weather and climate. NPS photo.

Nitrogen: A Stressor

Presumably a result of prevailing wind patterns, there has been a slow, steady increase in atmospheric nitrogen deposition in park watersheds (Lynch et al. 1995). In spite of increasing nitrogen deposition, however, there has been a decrease in dissolved nitrogen leaving watersheds (Melack et al. 1998b). These changes parallel an observed shift in the phytoplankton community of Emerald Lake in Sequoia—from a lake dominated by phosphorus limitation, to one dominated by nitrogen limitation. Mixed-conifer watersheds in Sequoia's Giant Forest have also shown net retention of nitrogen, with stream concentrations often below detection limits (Williams and Melack 1997a).

Elevated nitrate concentrations have been observed in lake and stream water samples from the upper Merced River watershed of Yosemite (D. Clow, pers. comm.). With continued urbanization of California's Central Valley, increasing livestock operations, and the possibility of transpacific N transport (and deposition) from Asia, it is probable that N deposition and its ecosystem effects in the high Sierra will increase over the next

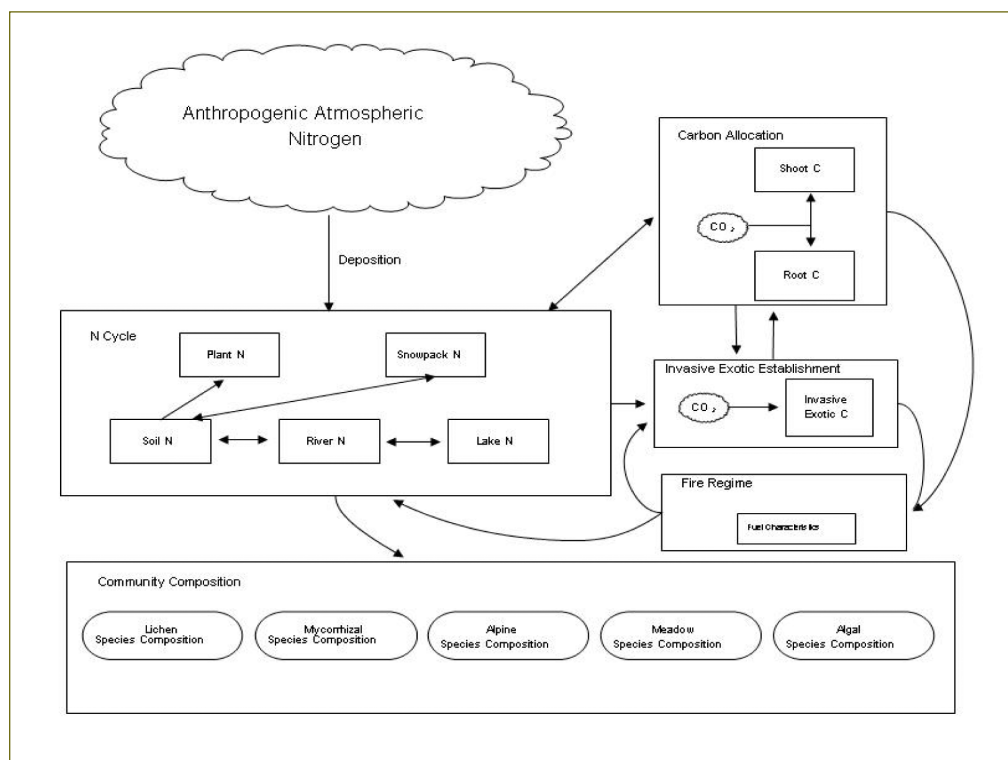


Figure F–11. Relationship of nitrogen deposition to other ecosystem processes and components.

several decades (Fenn et al. 2003).

The consequences of increased nitrogen deposition and retention on terrestrial plant communities in the Sierra Nevada are unknown, but greater foliar biomass production, resulting in enhanced litter accumulation on the forest floor (fuel) and in aboveground biomass (stand densification), may increase the risk of severe fire damage (Fenn et al. 2003). Nitrogen pollutants are likely to cause changes in lichen communities (e.g. shifts to nitrophilous species, changes in abundance) (Nash and Sigal 1999). Increased levels of soil nitrogen caused by atmospheric nitrogen deposition can increase the dominance of invasive alien plants and decrease diversity of native plant communities (Vitousek and Howarth 1991, Vitousek et al.

1997). Enhanced growth of invasive species, from increased nitrogen, has been observed in coastal sage scrub of Southern California, and is implicated in exacerbating invasion of Mediterranean non-native grasses (Allen et al. 1988). Changes in the alpine plant community of the Rocky Mountains from nitrogen deposition have been observed (Bowman 2000).

Vital Sign

Nitrogen deposition has the potential for deleterious effects to water chemistry (e.g., high-elevation lakes), selected plant communities (e.g., wet meadows and fens, lichens), and fire regime.

Through our vital signs monitoring program, we will include nitrate, dissolved organic nitrogen, total dissolved nitrogen, and particulate nitrogen as a measure of water chemistry (vital sign)

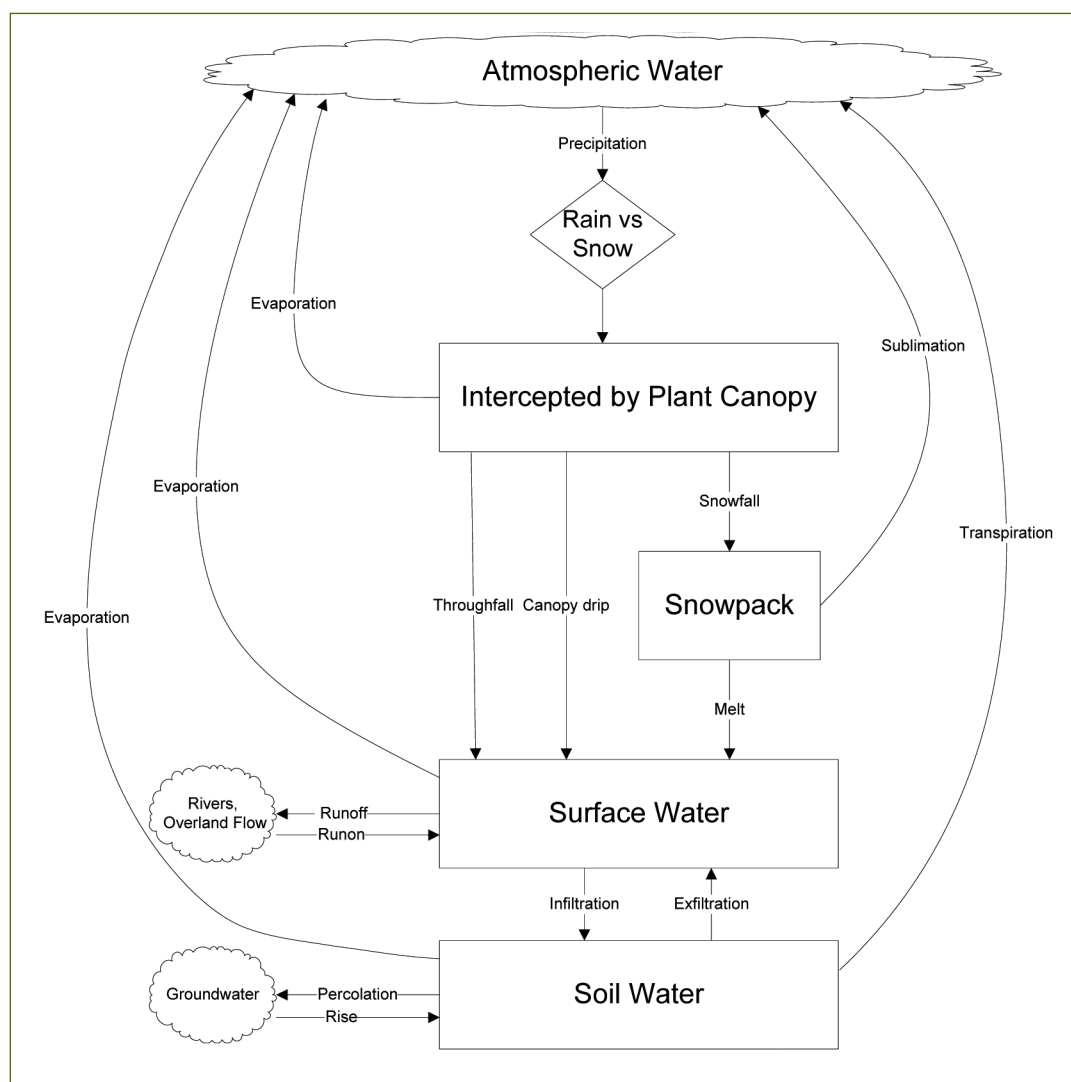


Figure F-12. Hydrologic system model for the Sierra Nevada.

monitoring in Sierra Nevada lakes.

To date, SIEN parks have conducted limited monitoring of nitrogen, through wet and dry deposition monitoring at a few air quality sites (see Appendix C, “Air Quality Synthesis”).

Model: Hydrologic System

Introduction

Components of the hydrologic cycle, such as evapotranspiration, are of great importance to plant growth and the main link between the hydrologic cycle and ecosystems.

Drivers, System Components, Functions

The hydrologic system is driven by atmosphere, climate, weather, geology, and topography. Our

hydrologic system model includes major pathways and stores for water in Sierra Nevada ecosystems (Figure F-12). This model depicts four major water storage compartments: water or snow intercepted on the plant canopy, snowpack, surface water, and soil water.

Most atmospheric water in the Sierra Nevada originates as water vapor from the Pacific Ocean. Precipitation may be intercepted by a plant canopy or pass through to the ground (throughfall for rain, or snowfall). Intercepted precipitation may be evaporated from the canopy or drip through to the ground. Plant canopies have a finite storage capacity that may not be exceeded by very small precipitation events, thus most rainwater from those events may be evaporated. Conversely, precipitation events exceed the storage capacity of the plant canopy, and most precipitation falls to the ground. Changes in vegetation composition and structure will alter the canopy storage capacity, thereby affecting evaporation, throughfall, etc.

Sierra Nevada snowpack is an important component of the hydrologic cycle because it is a natural reservoir that collects and stores water in the winter. The water is later released and available to ecosystems during the warmer and drier months. Loss of water from snowpacks is primarily by melting; however, sublimation (solid to vapor transport) also occurs under dry atmospheric conditions. Shortwave (solar) and long-wave (terrestrial) radiation are the main energy processes that contribute to snowmelt. However, rain-onsnow events can cause extensive and rapid melting, which can lead to flooding. The primary melting processes during these events are heat advection to the snowpack by rain, coupled with turbulent heat exchange between the atmosphere and snowpack (Dingman 2002).

Surface water describes any water on the surface that is free to flow, including overland sheet flow, streams, rivers, ponds, and lakes. Surface water is lost to the following: evaporation, infiltration into the ground, and overland flow (e.g., runoff). It may be gained through

precipitation events, by overland flow (e.g., runoff) from surrounding landscape elements, or by exfiltration of water from an underlying saturated substrate (e.g., a seep). Where surface water does not exist, it is relevant to think of that “model compartment” as storing zero water; thus, throughfall or snowmelt can directly infiltrate the soil. Infiltration of water into soil can be limited under two conditions. The first is that water arrives at the soil surface faster than the soil can absorb it. This results in standing water on the surface and the potential runoff of that water. The second condition limiting infiltration is when the underlying soil is at or near saturation. The lack of space for water storage hinders infiltration. In the higher Sierra where soils are sparse and thin, both mechanisms may operate to result in a high proportion of rainfall becoming runoff.

Soil water is gained by infiltration of surface water or by the rise of groundwater from below. Soil water is lost by evaporation, transpiration to the atmosphere, and by percolation to saturated soil below (groundwater). Evaporation of soil water is decreased by a cover of plant litter on the soil surface. Transpiration is the loss of water through the stomatal openings in plant leaves. Transpired water is replaced by soil water taken up through plant roots.

Losses from transpiration are generally much larger than evaporative losses in Sierra Nevada ecosystems. This can give rise to the seemingly paradoxical increase in soil moisture when trees are removed from an area and bare soil is exposed to the elements. When calculating water balances, these two processes can be difficult to separate and are often considered together as evapotranspiration. Evapotranspiration is responsible for a significant ‘loss’ of water from the landscape. In the U.S., more than two thirds of precipitation is returned to the atmosphere by evaporation from plants and water surfaces (Dunne and Leopold 1978). Evapotranspiration is of high importance to plant growth and the main link between hydrologic cycle and ecosystems.

Soil water can flow laterally. The lateral

flow of water in unsaturated soils is very slow compared to saturated flow, which in turn is very slow compared to overland flow of surface water. Numerous seeps and springs are fed by slow unsaturated as well as saturated soil water flow. Where unsaturated flow feeds into shallower soils those soils may become saturated and exfiltrate water to the surface.

Lakes, river, and stream ecosystems are discussed below, see “Aquatic System” models.

Stressors

The hydrologic system is intimately linked to the atmospheric system.

Changes in climate, and thus vegetation composition and structure, will alter the canopy storage capacity, thereby affecting evaporation and throughfall.

Snowpack has been decreasing over most of the West in recent decades (Mote et al. 2005), and spring stream flow has been occurring earlier (Stewart et al. 2004). Further, researchers in the Sierra Nevada have documented earlier snowmelt runoff, reduced summer base flows, and soil moisture (Dettinger et al. 2004, Dettinger 2005), and increased winter and spring flooding (Dettinger et al. 2004). There has been a trend towards lower snowpack volume at mid-elevations (Adam 1981, Knowles and Cayan 2001, Knowles et al. 2006), and smaller ratios of ‘winter-total snowfall water equivalent’ to ‘winter-total precipitation’ (Knowles et al. 2006).

Vital Signs

We selected several vital signs that capture various aspects of the hydrologic system. These include surface water dynamics (e.g., streamflow, lake volume), wetland water dynamics (e.g., wet meadow and fen groundwater level, soil moisture, surface flows), meteorological parameters (e.g., precipitation, solar radiation, air temperature), snowpack (i.e. depth and water content), and landscape mosaics (i.e. glacial extent, snow cover).

Model: Aquatic Systems

Introduction

The Sierra Nevada parks protect a

diversity of water resources, including over 4,500 lakes and ponds, thousands of kilometers of rivers and streams, seeps, wet meadows, waterfalls, hot springs, mineral springs and karst springs. Some of these aquatic systems have high biodiversity relative to the area they occupy in the parks (especially wetlands and meadows), some host endemic invertebrates (karst systems), and some provide habitat to sensitive and declining species (such as mountain yellow-legged frog in high-elevation lakes). Water dynamics in the Sierra Nevada are a critical component of both the parks’ ecosystems and the larger California water infrastructure. The snow pack acts as a temporary reservoir, storing water that will be released during the warmer and drier months.

Hydrology of the Sierra Nevada is dominated by the winter wet, summer dry Mediterranean climate. Persistent winter snowpacks at higher elevations result in peak runoff in late May to early June. Runoff usually continues through the summer to supply flow to streams, but is typically very low by summer’s end. Sierra Nevada ecosystems are adapted to drastic differences in water availability between seasons. As a result, temporal and spatial components of the hydrologic cycle are critical to these systems. Thus, hydrologic disturbances (drought, severe flooding) can have profound effects throughout the greater ecosystem.

In this section, aquatic system components, processes, and drivers (including the anthropogenic stressors) are described to provide a general framework for the aquatic vital signs. Three conceptual models are presented to describe major physical, chemical, and biological relationships of lotic and lentic systems in the SIEN:

1. Lake System
2. River & Stream System
3. Anuran Populations

Model: Lake System

High-elevation lakes are critical components of the parks’ ecosystems, popular visitor destinations, and habitat for aquatic and terrestrial organisms

including declining amphibian species. Lake ecosystems were selected for monitoring because they are valued for their ecological importance, recreational opportunities, and importance to regional water supplies, are threatened by multiple stressors and are sensitive to change. We will be monitoring three vital signs at high-elevation lake ecosystems: water chemistry, surface water dynamics, and amphibians.

The majority of Sierra Nevada Network lakes are located in the higher elevations (i.e., above 2500 m). Though a few lakes exceed 28 ha, most are only a few hectares in size and vary in depth from about 0.3 m to over 30 m. Sierra Nevada lakes are very dilute and characterized as oligotrophic, especially in the sub-alpine and alpine basins where there is sparse vegetative cover, shallow soils, and small contributing area. Sierra Nevada lakes have some of the lowest acid neutralizing capacity (ANC) concentrations in the

western U.S. (Eilers et al. 1989).

With low nutrient concentrations, these lakes still support a variety of aquatic fauna including zooplankton assemblages, micro-crustaceans, macro-invertebrates, fish (primarily non-native), and amphibians (Boiano et al. 2005). Three amphibian species (discussed below), Sierra Nevada and Sierra Madre yellow-legged frog (*Rana sierrae* and *R. muscosa*), and Yosemite toad (*Bufo canorus*), are candidates for listing as ‘endangered’. Current level of funding does not allow for a specific amphibian monitoring protocol; instead, we are working to integrate amphibian monitoring—at some level—into our Lake Monitoring Protocol).

Drivers, System Components, Functions—Lake Model

Lakes are a dynamic heterogeneous ecological system with characteristics that change over short and long

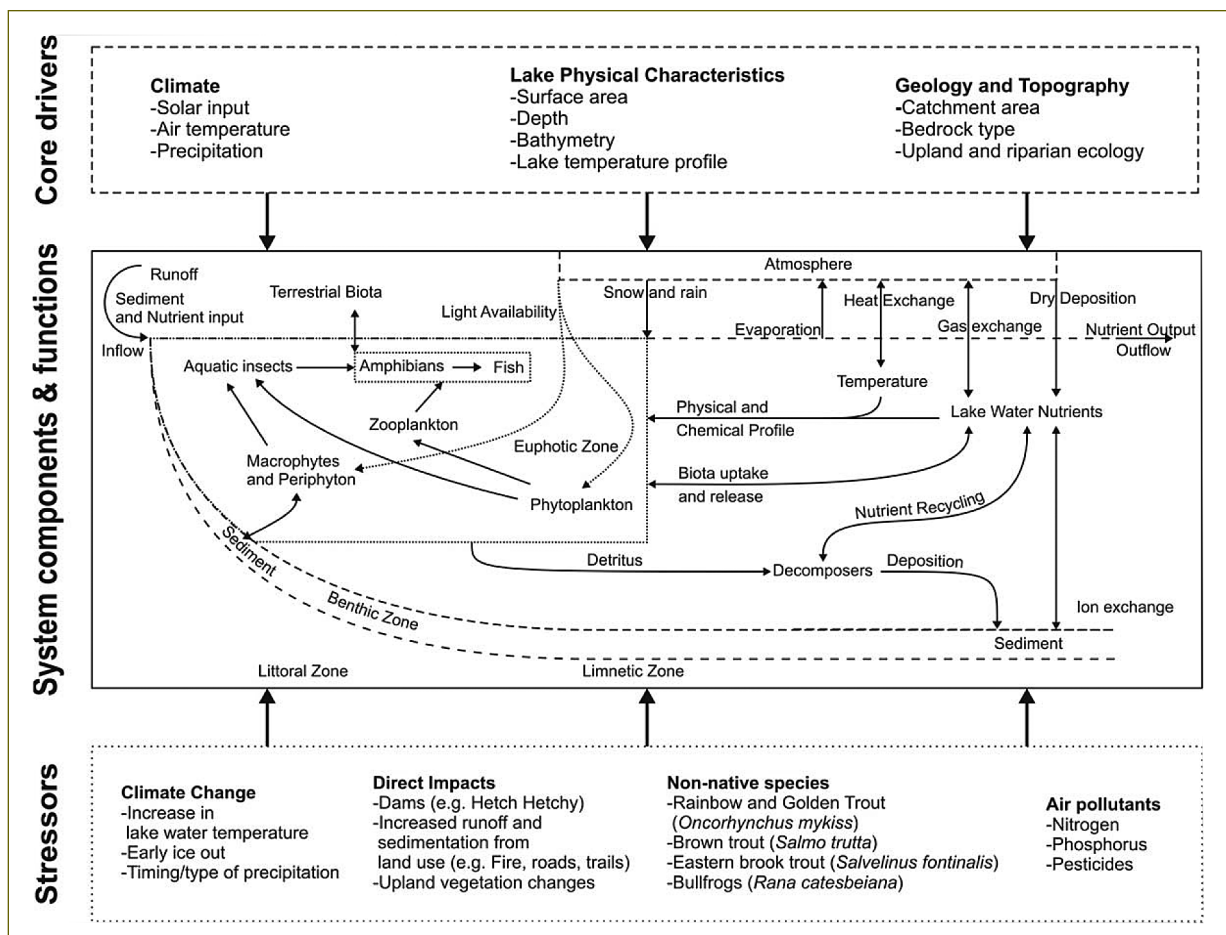


Figure F-13. Sierra Nevada Lake Conceptual Diagram.

time periods (Figure F-13). A lake is a function of its parent material, formation, and past climate evolving with present climatic conditions. Most lakes in the SIEN network are formed from glacial action. They were formed as glaciers scoured basins leaving a depression that was later filled with water. The watershed or drainage basin typically encompasses a small geographic area with shallow soil. Snowmelt is the primary water source. Geologic parent material, through weathering, provides ions to the lake system from overland and groundwater flow. The reduced soil contact and leaching of minerals produces the oligotrophic lakes in SIEN.

Climate is a core driver to the lake system. Precipitation provides the water source and timing of runoff inputs. Light drives the biotic lake processes. Light availability defines distinct lake zones where lake biota are linked to the unique topography of individual lake bathymetry. The euphotic zone is the depth in the lake where enough light penetrates to allow photosynthesis. This can be relatively deep in SIEN lakes because of water clarity. The littoral zone is where light penetrates to the lake bottom and rooted submergent, emergent, and floating aquatic plants or macrophytes and periphyton can grow. The limnetic zone is in the deeper waters of the lake where the sunlight needed for photosynthesis does not penetrate to the lake bottom. In the both the littoral and limnetic zones, phytoplankton are suspended in the water column and photosynthesize throughout the euphotic zone.

Water temperature is an important component of the lake ecosystem. The high specific heat of water allows for water to store large quantities of heat from the sun gained during the day and summer moderating lake temperature relative to air temperature. Water is less dense as a solid than a liquid, allowing for ice to form on the top of the lake. This insulates the lake allowing deep enough lakes to not entirely freeze. Water is most dense at 4° C (39° F). Following ice out, lake water temperatures are normally equal throughout the water column. Typically

the bottom waters are 4° C, and the temperature decreases toward freezing (0° C) at the lake surface. With the ice out, more solar energy can penetrate the top layer of water increasing the water density as the temperature approaches 4° C. As the water in the lake nears the same density it becomes easier for the lake water to mix. With the addition of wind mixing the water, and near equal densities, the entire lake can turnover and mix completely. Turnover can also occur by this same process when the lake cools. The process of turnover can happen multiple times in a year.

As the surface temperature continues to rise during the summer, the upper layer becomes warmer than 4° C and more buoyant, eventually becoming too buoyant to mix with the deeper water, forming distinct thermal layers. The lake is stratified by density into three distinct layers. The upper layer or epilimnion is warmest and well mixed. The mixed layer is primarily dependent on lake size and wind. The bigger the lake, the deeper the wind driven mixing occurs. The thermocline is the layer below the epilimnion where the water temperature declines quickly. The hypolimnion is the bottom layer consisting of the most dense water.

The basic physical and chemical properties of the lake are further influenced by the aquatic biotic system supported by the lake. SIEN aquatic biota consist primarily of fish, adult and larval anurans, several snakes and birds, a few mammals, a number of aquatic vascular plants, benthic algae, zooplankton and phytoplankton (lakes), bacteria, fungi, protists, and a large and diverse invertebrate fauna. In addition, foothill rivers include one species of salamander and turtle. Some of the largest aquatic invertebrate taxa include larvae of mayflies, stoneflies, caddis flies, and various dipterans; adult and larval beetles; amphipods; several mollusks; mites; nematodes; flatworms, and annelids. The numerous invertebrate insect taxa metamorphose into adult terrestrial organisms that disperse beyond the wetlands to provide food to upland species as well as serve other terrestrial functions. Recent work

here in SIEN supports the hypothesis that wetlands are extremely productive and have a large net export of food to upland areas (Holmquist and Schmidt-Gengenbach 2006).

While the above taxa occur in most SIEN waters, individual species' distributions vary with elevation. For example, large bivalves found in foothill streams (*Margaritifera* sp.) are represented by smaller bivalves in subalpine lakes (*Pisidium* sp.). The aquatic garter snake (*Thamnophis couchii*), which is common in the foothills, is replaced by the terrestrial garter snake (*Thamnophis elegans*) at high elevations.

Food webs within Sierra parks are complex. Aquatic invertebrates provide food for many of the vertebrate and invertebrate food chains (see Invertebrate Model, *infra*). This includes both predation directly within the aquatic environment (e.g., dytiscids eating odonate nymphs) and predation on metamorphosed adults in the upland world (e.g. flycatchers eating mosquitoes). Fish are one of the major predators of both aquatic and terrestrial insects. They collect insects drifting in the water column (e.g., Chironomidae) as well as terrestrial insects that can be taken near the water's surface (e.g., adult mayflies). At high elevations, mountain yellow-legged frogs play a significant role in the aquatic community. Besides being a major predator of metamorphosed insects and occasionally treefrogs, they are a source of food for other vertebrate predators like garter snakes (*Thamnophis elegans*), Clark's Nutcrackers (*Nucifraga columbiana*), and Brewer's Blackbirds (*Euphagus cyanocephalus*). Matthews et al. (2002) found a direct relationship between the abundance of garter snakes and mountain yellow-legged frogs.

Macrophytes (aquatic vascular plants), both submergent and emergent, provide multiple functions. In addition to providing basic photosynthesis and food for herbivorous fauna (e.g., meadow voles, Chironomids), macrophytes provide structure to aquatic habitat, cover for fauna, and substrate for periphyton (along with soil and rocks); they buffer erosion, absorb nutrients,

and contribute organic detritus when they perish. This detritus provides food and habitat for aquatic insects (e.g., Baetidae).

Sub-Model: Anuran Populations Introduction

Amphibians are sensitive to changes in ecosystem conditions, including: introduction of nonnative species and pathogens (i.e., trout, chytrid fungus), habitat fragmentation and degradation (e.g., from packstock grazing), water quality (e.g., from toxics such as airborne pesticides), and climate (e.g., global warming, changes in hydrology) (Figure F-14).

A recent Global Amphibian Assessment conducted by over 500 biologists (2000 to 2004) found that nearly one-third of all known amphibian species are globally threatened. The Assessment concluded that amphibians are currently more threatened than other vertebrate groups such as birds or mammals (Stuart et al. 2004). For North American fauna, amphibians have the second highest extinction rate (freshwater mussels being the first) (Ricciardi and Rasmussen 1999).

The loss of yellow-legged frogs is likely to have measureable impact on the natural functioning of lakes and streams within their historic range. Yellow-legged frogs are a sub-alpine and alpine predator (of primarily both aquatic and terrestrial invertebrates). They are also a major source of food for larger alpine predators such as western terrestrial garter snake (*Thamnophis elegans*).

Current funding does not allow for a separate amphibian monitoring protocol, but, because of their status and sensitivity as an indicator, we will integrate limited monitoring within our Lake Monitoring Protocol (see below; also, Appendix H, "Protocol Development Summaries").

Status of Anuran Populations

Two very rare, declining (State endangered; federal candidates for endangered status) yellowlegged frog species (*Rana sierrae* and *R. muscosa*) occupy upper elevations of SEKI and YOSE. Yellow-legged frogs were once

the most common vertebrate in the high elevation Sierra Nevada. (Grinnell and Storer 1924). Foothill yellow-legged frog (*Rana boylei*) formerly occurred in the foothills, but is now extirpated. Pacific treefrog (*Hyla regilla*) occurs at all elevations, in all parks. Yosemite toad (*Bufo canorus*) (State endangered; federal candidate for endangered status) breeds in ponds, wet meadows, along slow-flowing streams and ephemeral wetlands. Within SIEN, the species is found primarily in YOSE. It has also been documented in the northern portion of SEKI (Kings Canyon unit); however, distribution and abundance data are lacking. While not targeted within our Lake Monitoring Protocol, the Yosemite Toad (*Bufo canorus*) is endemic to the high Sierra Nevada. The Yosemite toad has disappeared from more than 50% of the sites where it was known to occur historically, and formerly large populations have been reduced in numbers (Jennings 1996).

Stressors

Disease

Amphibians are of particular concern because of an emerging infectious disease (chytridiomycosis, *Batrachochytrium dendrobatidis*) Chytrid fungus has now been determined as a proximate cause of mass mortality in both yellow-legged species (Rachowicz et al. 2006). Chytrid fungus has been found in Yosemite toads, including as early as 1970s (Speare and Berger, Green and Katarise-Sherman 2001, Vredenberg and Summers 2001); the impact of chytridiomycosis on population levels of this species has not been quantified.

Chytrid fungus had now been determined as a proximate factor in Sierra Nevada amphibian declines, causing death in post-metamorphic frogs (Rachowicz et al. 2005, Rachowicz et al. 2006) and infecting the keratinized mouthparts of tadpoles.

Non-native Species—Predation and

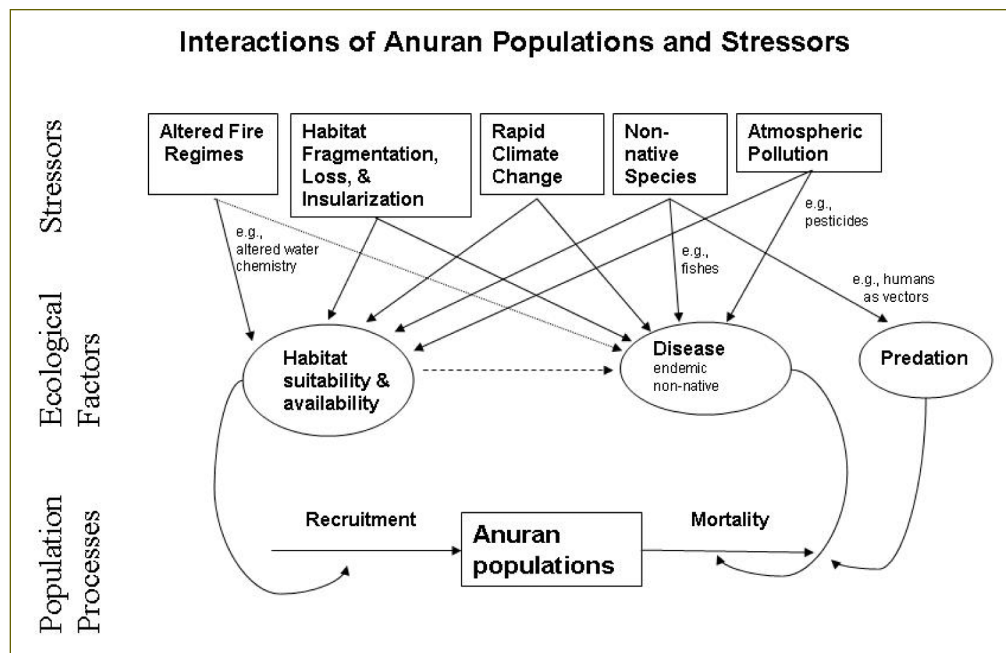


Figure F-14. Main interactions of anuran (frog and toad) populations and stressors.



Rainbow Falls, Devils Postpile National Monument. NPS photo.

Competition

Initially (i.e., before chytrid research), introduced fish were documented as a primary factor in declines of native lake-breeding amphibian species in the Sierra Nevada, including the precipitous decline of the yellow-legged frog (Bradford 1989, Bradford et al. 1993, Drost and Fellers 1996, Knapp and Matthews 2000, Knapp 2003a, Knapp 2003b, Knapp 2005).

While trout are the most prevalent of

the introduced aquatic biota, they are not the only alien species of concern. Bullfrogs (*Rana catesbeiana*), introduced from eastern and central states, exist in several network parks (typically at lower elevations). Bullfrogs threaten native amphibians by eating tadpoles and could impact future opportunities for restoration of foothill yellow-legged frogs (*Rana boylei*).

Toxics

Pesticides are also being examined in association with Sierra Nevada amphibian declines (Datta et al. 1998a, Sparling et al. 2001, Davidson 2004, Fellers et al. 2004). Of 11 western national parks studied as part of Western Airborne Contaminant Assessment Project, scientists detected the highest concentrations of pesticides in snow from Sequoia National Park (Hagerman et al., unpublished data, www2.nature.nps.gov/air/Studies/air_toxics/wacap.cfm).

Model: River & Stream System

SIEN parks span seven major watersheds: Tuolumne, Merced, San Joaquin, Kings, Kaweah, Kern and Tule. Runoff from these watersheds drains into the San Francisco Bay/Sacramento–

San Joaquin Delta in the north and the Tulare Lake Basin in the south.

Yosemite, Sequoia, and Kings Canyon parks contain most headwater streams for these watersheds. Devils Postpile National Monument is located within the upper Middle Fork of the San Joaquin watershed. The headwaters of the Middle Fork of the San Joaquin begin 14.1 km upstream of the monument at Thousand Island Lake. The watershed area above the monument is managed by Inyo National Forest.

Flow in Sierra Nevada rivers and streams is highly variable in time, both within and between years. Peak flows can be up to five orders of magnitude greater than minimum flows. Annual volumes can be twenty times greater in very wet years than in very dry years (Kattelmann 1996). Some smaller streams cease flowing during prolonged dry periods.

High water levels are an integral feature of Sierra Nevada Rivers and have a variety of effects on aquatic biota as well as channel morphology (Erman et al. 1988, Kattelmann 1996). Peak flows in the Sierra Nevada result from snowmelt, warm winter storms, summer and early-autumn convective storms, and outbursts from storage (Kattelmann 1990). In rivers with headwaters in the snowpack zone (true of all SIEN rivers), snowmelt floods occur each spring as periods of sustained high flow, long duration, and large volume. Midwinter rainfall on snow cover has produced all the highest flows in major Sierra Nevada rivers in the past century (Kattelman et al. 1991). The last such flood of this type with high impacts to SIEN parks' infrastructure and aquatic systems occurred in January 1997 (Figure F–15).

At the other extreme, stream flow into Sierra Nevada rivers can become quite low during intense or extended droughts. The past two decades have included record droughts for one year (1977), two years (1976–1977), three years (1990–1993), and six years (1987–1992). Total stream flow averaged across many Sierra Nevada rivers was about half of average in each case (Kattelmann 1996). Changes in precipitation type and timing that are expected with climate



Figure F–15. Yosemite Valley campground during flooding event in the Merced River, January 1997 (100-year flood). Such floods are predicted to increase due to climate change in the Sierra Nevada (Knowles et al. 2006). Photo by Steve Thompson.

change will result in longer and drier summers with less water available for ecosystems and regional economic uses.

The Sierra Nevada is generally regarded as producing surface water of excellent quality, meaning the water is suitable for almost any use and contains lower amounts of contaminants than specified in state and federal standards. Most runoff would be suitable for human consumption except for risk of pathogens (Kattelman 1996). Very little of the water of the Sierra Nevada can be considered highly polluted (i.e., contaminated with materials having potential adverse effects at concentrations above background level).

Areas of lower water quality correspond to those areas with greater human activities and access. While SIEN park waters are of high quality compared to waters in agricultural and urban areas in the state, there are still a number of threats to park water quality that will be discussed in the Drivers section below.

Drivers, System Components, Functions—River & Stream Model

SIEN streams encompass the headwaters of seven major watersheds. These watersheds, from north to south, are the Tuolumne, Merced, San Joaquin, Kings, Kaweah, Tule and Kern. Runoff from these watersheds drains into the San Francisco Bay/ Sacramento–San Joaquin Delta in the north and the Tulare Lake Basin in the south. Our stream system model includes core drivers, system components and functions, and stressors (Figure F-17).

Stream processes in SIEN parks are driven by the Mediterranean climate and snow melt. Peak runoff is typically May–June (Figure F-16) and punctuated by large flood events (e.g., January 2007). See the Hydrologic System Model, supra, for more detailed discussion. Water chemistry has a spring pulse of ions flushed from the snowpack during the early stages of spring melt. The low ionic strength of the stream waters are susceptible to changes in atmospheric inputs, and increases from fire in the catchment.

Streams move water, sediment, and

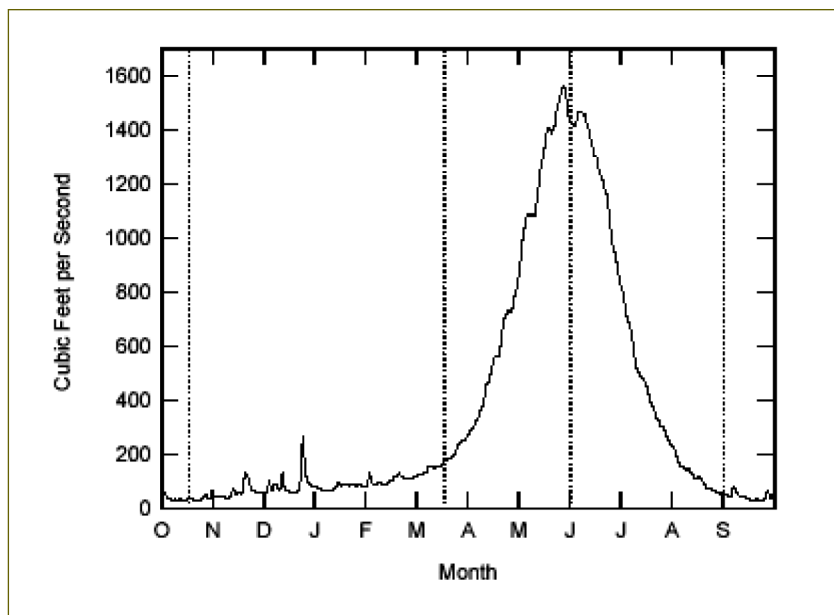


Figure F-16. Representative mean annual hydrograph from the Merced River at Happy Isles in Yosemite National Park. National Park Service—Water Resources Division plotted the hydrograph using a 72 year record (National Park Service 1998). Vertical lines divide the hydrograph into four seasons.

nutrients altering landforms with erosion and deposition. The stream system receives inputs from precipitation into the watershed basin, and moves water and sediments downstream shaping the landscape through fluvial processes. Stream processes alter existing landforms, reducing topographic relief.

Stream water is a function of direct precipitation to the stream channel, runoff from the basin, evapotranspiration, and groundwater flow. Over time, geology and topography define the drainage pattern. Streams develop onto areas that are less resistant to erosion.

Erosion drives the stream load which is comprised of the dissolved load, suspended load, and bed load. Most organisms are near or on the substrate, and are largely dependent on flowing water.

Slope and sediment availability define the channel type. A stream with little slope, fine sediments, and strong bank cohesion will usually have a meandering stream channel. A stream with coarse sediment tends to have a braided channel. The stream's "long" profile generally is concave up with headwater slopes typically steeper than those near the stream mouth.

In-channel stream processes are dynamic, adjusting the stream-wetted perimeter in a response to stream competency, sediment size, grade, and water velocity. Headwaters typically have a high stream velocity, moving larger sediments both along the bed, and in suspension with turbulent flow through a V shaped valley. As the stream flows into lower gradient areas stream competence is lowered. The stream velocity decreases, turbulent flow is not enough to support the larger suspended particles, which are deposited creating a braided channel. The aggradation spreads the stream flow across a greater wetted perimeter allowing more of the heavier sediments to be moved as bed flow.

As the stream flows farther into lower-slope areas, finer sediments dominate the stream capacity. The finer sediments are suspended and transported with lower flow creating a more sinuous stream channel. A meandering stream is

U shaped, and has a high sinuosity

ratio—it travels a much farther distance through the channel when compared to linear travel distance. A straight channel has a low sinuosity ratio. The spiral flow of the stream creates a preferential outside bank cut and depositional point bar on the inside bank.

Meandering rivers create fluvial landscape features such as back swamps, wetlands, and oxbow lakes. SIEN streams show meandering stream characteristics in wetland (i.e., wet meadow) areas such as Yosemite Valley, and Tuolumne Meadows supporting a large diverse riparian area.

Riparian systems form a dynamic and intricate buffer strip along stream banks between base-flow and high water levels. The riparian zone helps slow runoff and is an important nutrient source and sink. Riparian vegetation provides bank stabilization, organic matter input such as

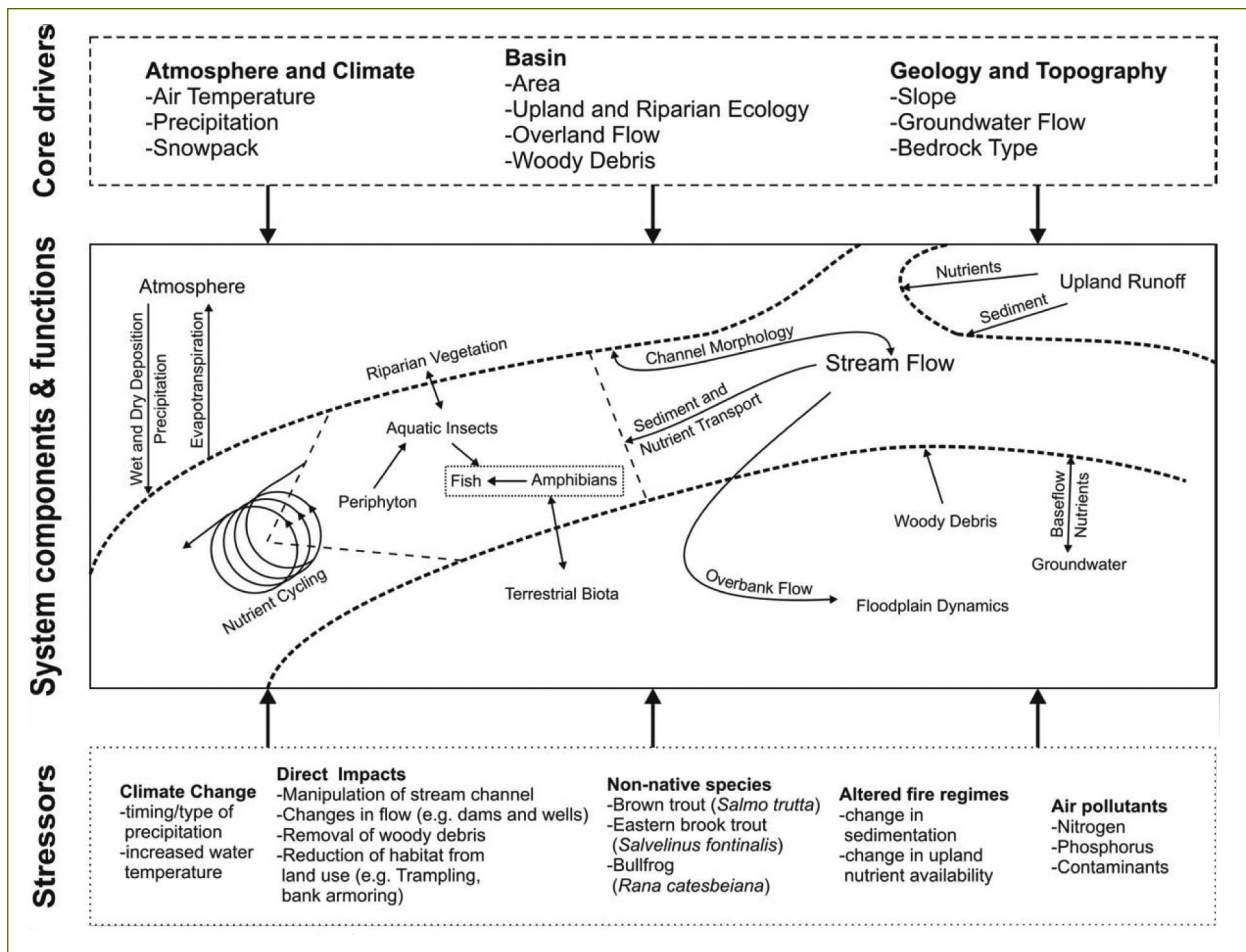


Figure F-17. Sierra Nevada river and stream conceptual diagram.

woody debris, and habitat. Large terrestrial woody debris alters channel hydraulics and provides unique aquatic habitat.

Periphyton and riparian vegetation cycle nutrients delivered by the stream system.

Aquatic organisms, including microorganisms and mayfly nymphs, break down organic matter, and are a food source for fish and amphibians creating a spiraling effect on stream nutrients of storage in stream biota and transport in stream flow. Nutrients are accumulated by aquatic organisms and cycle between organic and inorganic forms while slowly being moved downstream with spiral length being an indicator of metabolic activity.

Aquatic System Stressors: Lakes, Rivers & Streams

Aquatic systems are among the most altered ecosystems in the Sierra Nevada (SNEP 1996). Introduced alien invasive species caused much of this alteration. For over a hundred and thirty-five years, trout were planted in park waters, both in areas that contained native fish populations and in waters that were naturally barren of fish (Christensen 1977). The effects of these introductions on lentic environments have been to eliminate large zooplankton (e.g. *Hesperodiaptomus* sp.), (Stoddard 1987, Bradford et al. 1998) and open-water insects (e.g., Corixidae).

When comparing streams with and without introduced trout, Herbst et al. (2003) found streams with introduced trout to have more and denser algae cover, more midges, and reduced density of *Doroneuria baumanni*, a stonefly that was probably the dominant predator prior to trout introductions. Native fish were impacted directly by competition with introduced brown trout (*Salmo trutta*) and eastern brook trout (*Salvelinus fontinalis*), and by genetic introgression from introduced genotypes of rainbow and golden trout (*Oncorhynchus mykiss*). Little Kern golden trout (*Oncorhynchus mykiss whitei*) became federally listed as threatened after being nearly extirpated by introduced trout. Knapp (2005b) found an inverse relationship

between the presence of introduced fish and garter snakes. This is likely due to introduced trout eliminating a major source of the garter snake's diet, i.e., mountain yellow-legged frogs. Introduced fish impacted the distribution and abundance of the mountain yellow-legged frogs (Knapp and Matthews 2000) by eating their larvae and some adults, by displacing frogs from deep lakes critical to their winter survival, and by fragmenting populations which destroyed functionality of their metapopulations.

In addition, mountain yellow-legged frogs have experienced dramatic population losses from a newly discovered fungus, *Batrachochytrium dendrobatidis*, which causes chytridiomycosis, a condition that destroys keratin in frog skin and results in death. This fungus was only discovered in the early 1990s, and the current available information suggests that it too has been introduced (Weldon et al. 2004, Rachowicz et al. 2005). The parks' waters receive considerable input from agricultural pesticides (Cory et al. 1970, Zabik and Seiber 1993, Aston and Sieber 1997, Datta et al. 1998a, Datta et al. 1998b, McConnell et al. 1998, LeNoir et al. 1999, Angerman et al. 2002). It is not known if these chemicals weaken a frogs' susceptibility to chytridiomycosis, but recent studies have showed endocrine disruption (Sparling et al. 2001, Fellers et al. 2004). Further, there exists an inverse relationship between pesticide use and downwind occurrence of frog populations (Davidson 2004).

While trout are the most prevalent of the introduced aquatic biota, they are not the only alien species of concern. Bullfrogs (*Rana catesbeiana*), introduced from eastern and central states, exist in several network parks. Bullfrogs threaten native turtles by eating their young (Jennings and Hayes 1994), and could impact future opportunities to restore foothill yellow-legged frogs (*Rana boylei*). A non-native amphipod (*Hyaella azteca*) was introduced into the Rae Lakes, and now they have become the most abundant species in plankton tows (Silverman and Erman 1979). On the North Fork Kaweah, *Potamogeton*

crispus, a plant from Eurasia, has become common and may be competing with native *Potamogeton* sp..

As mentioned, SIEN parks have some of the worst air quality in the country (Peterson and Arbaugh 1992, Cahill et al. 1996). Among air contaminants, are ionic forms of nitrogen that contribute to episodic pH depression and to nutrient deposition in both upland and aquatic systems. Effects of acidification on aquatic systems were examined on aquatic systems in the Emerald Lake basin in the 1980s. In lentic environments, Sickman and Melack (1989) found no inhibition of phytoplankton growth above a pH of 4.0. Certain species of zooplankton (e.g., *Daphnia rosea* and *Diaptomas signicauda*) virtually disappeared when pH was reduced below 5.0, but density of certain other species increased with certain levels of acidification (e.g. *Kerotella taurocephala* and *Bosmina longirostris*), probably due to a lack of competition from *Daphnia rosea* (Melack et al. 1989). Melack et al. (1989) did not find a relationship between benthic invertebrates and acidification. In lotic environments, acidification down to pH levels between 4.6 and 5.2, for time periods of 6-8 hours, increased insect drift and the proportion of dead organisms within the drift (Hopkins et al. 1989, Kratz et al. 1994), though different taxa showed different levels of susceptibility and some groups showed no response to acidification (Kratz et al. 1994).

Climate

Most atmospheric water in the Sierra Nevada originates as water vapor from the Pacific Ocean. This moisture is transported across California and precipitated as rain or snow.

Rain is the dominant precipitation type at the lower elevations (less than 1,500 m) and snow is the dominant type at higher elevations (above 1,500 m). Warming climatic conditions have the most potential to alter snowpack storage; current models predict lower snowpack volume at mid-elevations (Knowles and Cayan 2001) and earlier melting at all elevations (Dettinger 2005). Glaciers,

which store water year-round, have been shrinking throughout the west for the past several decades (Basagic).

Air Pollutants

Contaminants and nutrients, produced from agricultural, urban, and industrial sources in the San Francisco Bay Area and the Central Valley, are transported by air currents into the Sierra Nevada where they are deposited as wet or dry deposition. Increased nitrogen deposition in the Transverse Ranges of southern California, low elevations in the southern Sierra Nevada, and high-elevations in the Colorado Rocky Mountains has already led to excessive leaching of nitrate into receiving waters (Fenn et al. 2003).

Elevated nitrate concentrations in streams are a primary symptom of N-saturated ecosystems (Fenn et al. 1998). High elevation lakes and streams in the Sierra Nevada are especially sensitive to change from atmospheric deposition because the waters are oligotrophic and have a low buffering capacity. In addition, alpine watersheds have a low capacity to retain nitrogen primarily due to steep talus slopes, shallow soils, and sparse vegetation. Changes in nutrient cycles and shifts in phytoplankton communities in Sierra Nevada lakes have been detected and attributed to increased nitrogen and phosphorous inputs (Goldman et al. 1993, Sickman et al. 2003). Rates of nitrogen loss and their controlling mechanisms vary along the elevational gradient. Mid-elevation mixed-conifer forests, especially giant sequoia, are more effective at retaining nitrogen than ecosystems near the elevational extremes (e.g. chaparral and alpine) (Stohlgren 1988, Melack et al. 2002, Fenn et al. 2003).

Pesticides from the adjacent Central Valley (LeNoir et al. 1999) and global sources (National Park Service Air Resources Division 2003) have been detected in Sierra Nevada streams and lakes at all elevations. The extent of the effects on aquatic ecosystems is largely unknown; however, current research suggests that pesticides may be a threat to aquatic species, including declining amphibian populations (Sparling et al. 2001, Davidson and Shaffer 2002).

Altered Fire Regime

Over 100 years of fire suppression policies have altered fire regimes in the Sierra Nevada Network parks. In general, fire frequencies have decreased and the potential for higher severity wildfires has increased (Swetnam 1993, Caprio and Lineback 1997, Caprio 2004).

Potential effects on water resources from a lack of fire are reduced stream flows, changes in biogeochemical cycling and decreased nutrient inputs to aquatic systems (Chorover et al. 1994, Williams and Melack 1997b, Hauer and Spencer 1998, Moore 2000). Less frequent but higher severity wildfires have the potential to impair water resources. Potential impacts include increased flooding, erosion, sediment input, water temperatures, and nutrient and metal concentrations (Tiedemann et al. 1978, Helvey 1980, Riggan et al. 1994, MacDonald and Stednick 2003). Deposition of ash particles in the surrounding landscape may contribute to increasing nutrient inputs to oligotrophic waters (Spencer et al. 2003).

Since 1968 and 1970, Sequoia and Kings Canyon, and Yosemite National Parks have used fire extensively as a tool to reduce fuel loads and restore the natural processes of fire to park ecosystems (Caprio 1999). Although the parks' fire management programs made significant progress in the last 35 years, altered fire regimes are still considered one of the largest threats to the parks' ecosystems (Sequoia and Kings Canyon National Parks 1999). Changes in fire frequency and intensity affect sediment transport, water chemistry including nutrient dispersal, water quantity by altering evapotranspiration, and stream canopy cover which in turn affects light penetration and water temperature.

Chan (1998) found that increased fine sediment input caused by prescribed burns reduced macro-invertebrate diversity the following year. Water quality research in the parks has focused on the effects of prescribed burning on hydrology, stream chemistry and nutrient cycles. Increases in stream flows and solute concentrations were detected following prescribed fires in headwater streams of Sequoia National

Park (Williams and Melack 1997b, Heard 2005). However, solute concentrations were still well below levels that would threaten aquatic ecosystems. Long-term monitoring with repeated prescribed burning are needed to determine if these increases were within the natural range of variability. Effects of prescribed burning on stream flows or water quality have not been detected at the landscape scale (Heard 2005). The effects of a large, high-severity wildfire are likely to be more pronounced and detectable at larger scales.

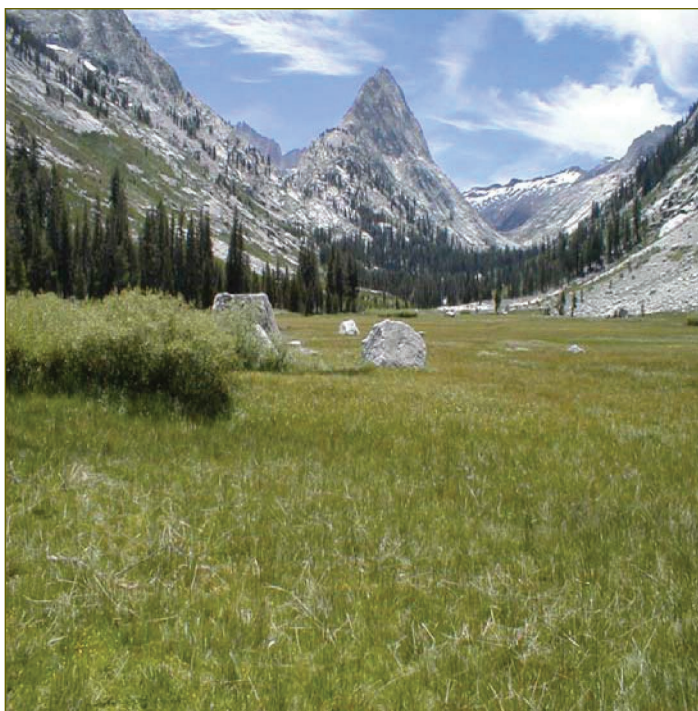
Direct Impacts: Impoundments and Dams

Six major water impoundments occur in SIEN parks. There are four large impoundments within Sequoia National Park. All four were built on existing lakes in the upper East Fork of the Kaweah River in the early 1900s and are currently operated by Southern California Edison. Numerous small impoundments also exist in small creeks primarily used for water supplies. There are at least 18 water diversions and seven wells within the park boundary.

Yosemite National Park contains two major impoundments: Hetch Hetchy (4.45 x 108 m³) and Lake Eleanor (3.34 x 107 m³). Hetch Hetchy, which impounds the Tuolumne River, was created in 1938 with the completion of O'Shaughnessy Dam. Hetch Hetchy Reservoir is part of the larger Hetch Hetchy Regional Water System that supplies drinking water to the City of San Francisco and irrigation water to the Central Valley.

Lake Eleanor was created in 1918 and the water is used primarily for hydroelectric power. Cascades Dam, located on the Merced River downstream of Yosemite Valley since 1918, was recently removed and the river corridor restored. Numerous small dams and diversion are located throughout the park; most of these are associated with the High Sierra Camps.

SIEN parks have numerous wells for drinking water sources. Most of the larger wells are located in various developed areas in the parks. Groundwater pumping from wells located in Yosemite's Doghouse Meadow and potentially other park fens



Big Wet Meadow, Kings Canyon National Park. NPS Photo.

are changing the soil and vegetation type in sections of these wetlands (see Heard and Stednick, and also, Appendix C, “Air Quality Synthesis”).

Areas of general park operations or high visitor use are sources for nutrient and contaminant inputs to aquatic systems. Sources include sewage treatment plants, pack stations, campgrounds, roads, and popular swimming holes. Elevated concentrations of nutrients have been detected downstream of park spray fields (Sequoia And Kings Canyon National Parks 1999b), and fecal coliform counts have been observed in popular Yosemite swimming holes (Williamson et al. 1996). However, at a larger scale, research in Sierra Nevada wilderness lakes, rivers, and streams shows concentrations of coliform and other human pathogens are very low (Derlet and Carlson 2002, 2003).

Recreational and administrative packstock grazing in wetlands/meadows within SIEN parks can affect aquatic systems through effects of trampling, erosion, and additional nutrients on wetland systems and adjacent lakes and streams. Human use has also had measurable impacts to aquatic biota. Taylor and Erman (1979, 1980) found that growth of aquatic macrophytes and benthic invertebrates increased

with increasing human use of lakes, and hypothesized that growth stimulation was from plant nutrients acquired from human presence.

Potential acid rock drainage from abandoned mines in the upper San Joaquin River watershed above Devils Postpile and in the Mineral King area of Sequoia National Park could degrade water quality in portions of these watersheds. Impacts on water quality have been observed from one mine in Sequoia. Impacts from other mines and cumulative impacts at a larger scale have not been quantified.

Vital Signs—Lakes

The SIEN plans to monitor water chemistry and surface water dynamics (or flow) in selected lakes, rivers, and streams. Flow (or discharge) is the most fundamental aspect of watershed hydrology (Figures F-13 and F-17).

Water chemistry components measured will include: pH, dissolved oxygen, specific conductance, temperature, major ions, acid neutralizing capacity, nitrate, dissolved organic nitrogen, total dissolved nitrogen, total dissolved phosphorus, particulate nitrogen, particulate carbon, particulate phosphorus.

Surface-water dynamics’ measures include: lake outlet discharge lake elevation, lake volume. Phenological measures, including timing and duration of ice-out and ice-up, may be included as part of our Landscape Dynamics protocol, if possible.

Relative anuran abundance (adults, tadpoles, egg masses) and species distribution are measures for three targeted amphibian species: Sierra Nevada and Sierra Madre yellowlegged frogs, and Pacific treefrog.

Vital Signs: Rivers & Streams

River and stream indicators have not yet been determined, but will occur during protocol development (see Appendix H, “Protocol Development Summaries”).

Water chemistry components have not yet been selected, but surface water dynamics measures will include stream

discharge (peak flow/low flow/water yield) and qualitative estimate of flow relative to bank full.

Model: Wetlands

Introduction

Wetlands are the boundary between aquatic and terrestrial ecosystems. They are a transition zone with an important role in biogeochemical cycles (especially carbon, nitrogen, sulfur). This interface creates an area of high biodiversity, which is sensitive to local, regional, and global stressors, making wetlands a unique ecosystem focal point to monitor.

Wetlands are diverse and complex ecosystems varying widely in character and composition although they occupy only a small fraction (<1%) of the land surface of the Sierra Nevada (Benedict and Major 1982, Ratliff 1982). Sierra Nevada wetlands range in size from small patches to large expanses, such as Tuolumne Meadow in Yosemite.

Despite this variability, the processes that

govern the creation and maintenance of wetlands can be generalized in a simplified model. Our conceptual model illustrates the main functions, components and processes operating in Sierran wetlands (Figure F-18), and the key drivers and stressors affecting these systems (discussed below).

Wetlands are a hydro-geologic concept: (1) they are ecosystems with seasonally or periodically saturated and anoxic soils, and (2) their hydrologic regime is driven by surface and/or ground water. In addition to hydrology and hydric soils, wetlands are characterized by vegetation.

There are several major types of wetlands in the Sierra Nevada (and mountain regions throughout the world). In SIEN, we classify wetlands according to Cooper et al. (Cooper et al. 2005):

Dry Meadows: too dry to support trees due to a steep gradient or south facing aspect, summer aridity; fine grained or gravel soils, and competition for water that allows grasses to

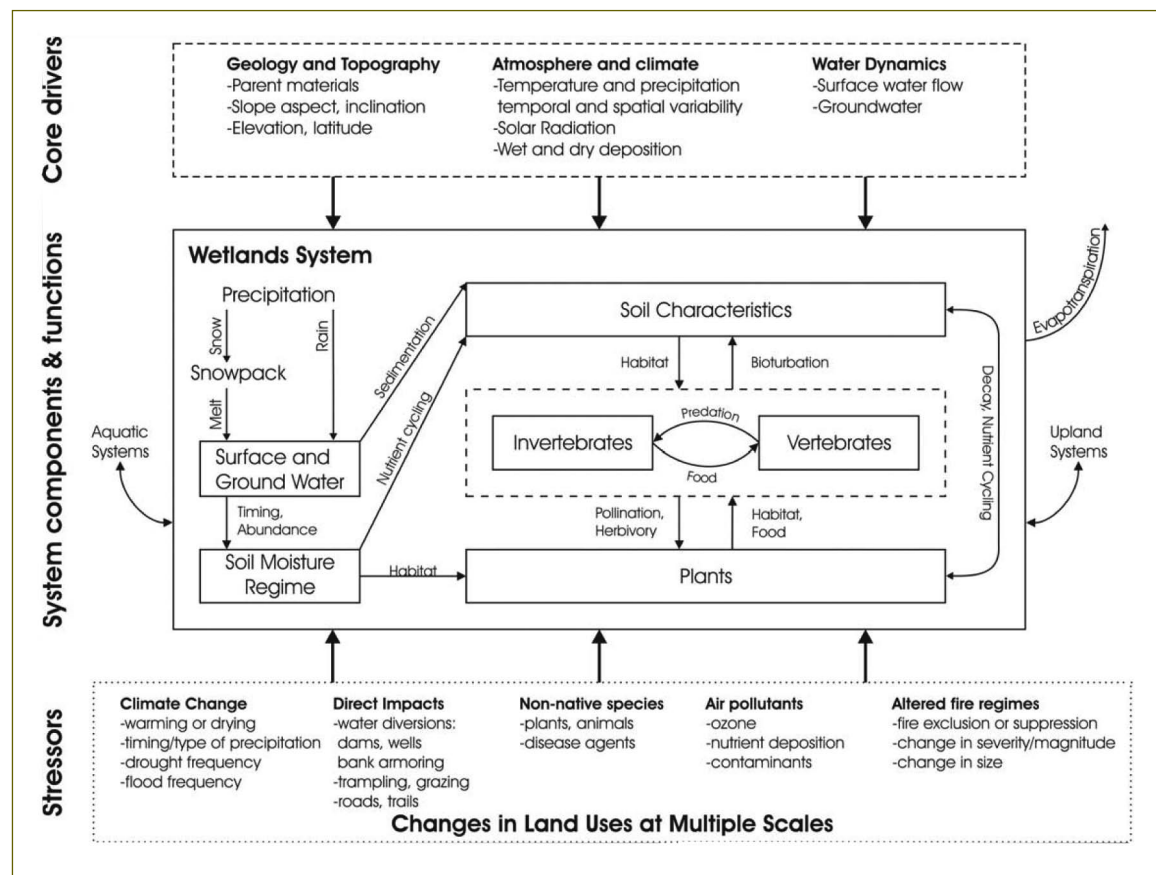


Figure F-18. Wetland system conceptual diagram.

dominate.

Wet Meadows: typified by seasonal saturation or flooding, high water tables, mineral soils, and too wet to support most tree species.

Riparian Meadows: driven by hydrologic and geomorphic processes of streams or rivers.

Fens: perennially saturated and anoxic soils (limits organic matter decomposition), organic matter production > decomposition, organic matter accumulates (average ~20 cm/1000 yrs), peat accumulation creates landforms, numerous fen types.

Drivers, System Components, Functions

Wetlands are a vital sign for long-term monitoring in the Sierra Nevada because of their high biodiversity relative to area occupied, and the important ecosystem, cultural, and social functions they provide. Sierra Nevada wetlands have the following functions (Williams 1990, Mitsch and Gosselink 1993):

- Influence regional water-flow regimes including flood mitigation by intercepting and slowing the release of water to streams
- Improve water quality by removing nutrients and toxins
- Trap sediments
- Are highly productive
- Provide important habitat for wildlife
- Have aesthetic value to the people who visit them

Core drivers of Sierran wetlands include geology and topography, atmosphere and climate, and water dynamics.

Geology and topography create the physical structure necessary to produce a wetland. Glaciation, sedimentation, and fluvial processes establish the basic landscape needed to develop a wetland. Geologic parent material defines some of the physical parameters of a wetland such as hydraulic conductivity and nutrient availability from weathering. Local topography such as slope, aspect, and inclination affect runoff rates, precipitation distribution, snow load, and solar input.

Elevation and latitude affect precipitation amounts, snow pack, and snow melt timing. Atmosphere and climate determine the amount and type of precipitation. Timing and amount of precipitation primarily drives the inundation of wetlands. Nutrient, water, and sunlight availability combine to provide the unique wetland habitat niche where wetland plants can dominate.

Wetlands form in level to near-level catchments, where soils are saturated or inundated at least part of the year, as in basins formerly occupied by glacial lakes or along perennial stream courses. Prolonged saturation of the soil creates an anaerobic environment. When saturation is combined with microbial activity, oxygen is depleted creating a reducing environment. The anaerobic environment produces wetland soil characteristics such as a thick layer of organic matter from slowed decomposition in the upper soil profile, and oxidized root channels, gleying, and mottling from the reduction and translocation of elements such as iron and manganese. The resultant hydric soil supports hydrophytic vegetation that is an attribute of a functioning wetland.

Sierran wetlands occur in basins, on slopes, along streams, and adjacent to lakes and ponds. Wetlands generally occur above snowline, where snow (namely snowmelt) provides moisture during the summer growing season. In addition to surface flow, moisture enters wetlands from rivers, streams, and sub-surface flows forced to the surface by local geomorphology. Meadows are characterized as wet, moist or dry, reflecting the relative availability of moisture during the summer growing season.

Solar radiation provides the energy to physically and biologically drive the system. Amount, duration, and intensity of solar radiation determine temperature, growing season, and rate of evapotranspiration. Ambient temperature dictates whether precipitation is rain or snow, and the timing and speed of snowpack melt. Sierra Nevada wetlands generally occur above snowline, where snow pack

determines the length of the growing season, and snowmelt provides moisture during the summer growing season.

Wetlands provide important ecological and cultural functions. Some of the functions described by Mitsch and Gosselink (1993) and Williams (1990) that apply to Sierra Network wetlands include: (1) influencing regional water-flow regimes, including flood mitigation, by intercepting and slowing the release of water to streams, (2) improving water quality by removing nutrients and toxic materials, (3) sediment trapping, (4) sources of some of the highest productivity in the world, (5) important habitat for wildlife, and (6) aesthetic values to people. Peat-accumulating wetlands, in their natural condition, remove and store carbon. If altered, such as by drainage, the process would reverse contributing to atmospheric carbon dioxide through oxidation (Gorham 1991). Wetlands also play an important role in nitrogen and sulfur cycles.

Wetland areas typically slow surface water flow allowing for increased sedimentation and infiltration during peak flows. They serve as a reservoir for water that is slowly expended through drier seasons. In addition to surface flow, moisture enters wetlands from sub-surface flow forced to the surface by local geomorphology. Geologic parent material helps to determine permeability, infiltration, and pore space that control water flow through the hydric soil.

Nutrients weathered from upland landscapes are transported in surface and sub-surface water and delivered to wetlands along with nutrients scavenged from the atmosphere as wet and dry deposition. These nutrients are cycled by biota, and leached in surface and subsurface flows. Additional nutrients are moved into and out of wetlands as fauna move between upland and wetland areas. In organic soils, the anaerobic conditions usually allow for accumulation to exceed decay resulting in a thick muck or peat layer. In mineral soils, elements can be reduced and leached or reduced and reoxidized depending on the length of time the soil is saturated.

Sierra Nevada wetland vegetation is

dominated by perennial graminoids, which reflect the relatively short growing season of the middle and high elevations. Key genera include *Carex*, *Deschampsia*, *Calamagrostis*, *Juncus*, *Danthonia*, and *Eleocharis*, with species composition of individual wetlands determined by local moisture regime and soil characteristics. Annual productivity of wetland graminoids is closely tied to the amount and timing of winter snows as well as changes in length of growing season associated with such fluctuation; when late lying snows shorten the growing season, productivity declines accordingly. Upland woody plants are generally excluded from wetlands because of seasonally saturated soils. However, willows (*Salix* spp.) are frequently found along stream channels and often form patches within wetlands. Lodgepole pine, *Pinus contorta*, with a high tolerance for saturated soils, is commonly encountered in and adjacent to wetlands—taking hold during dry years and giving way to wetland vegetation under wetter conditions, in a cycle of invasion and retreat.

Wetlands provide critical breeding and foraging habitat for a suite of animal species. Mule deer take advantage of the cover provided by montane wetland vegetation by hiding their fawns under the dense herbaceous canopy. Small mammals, such as Belding ground squirrels, pocket gophers, deer mice, and voles, feed on wetland vegetation, and ground squirrels and pocket gophers play a significant role in soil perturbation. Frogs and toads may breed in wetlands, and shrews frequent the moist vegetation preying on insects and other invertebrates.

A number of bird species, such as the federally endangered Willow Flycatcher (*Empidonax trailii*) and state-endangered Great Grey Owl (*Strix nebulosa*), use Sierra Nevada wetlands for foraging, nesting, or both. Mule deer take advantage of the cover provided by montane wetland vegetation by hiding their fawns under its dense herbaceous canopy. Small mammals (e.g., ground squirrels, mountain beaver, pocket gophers, and voles), feed on both above- and below-ground wetland



Sampling invertebrates in Tuolumne Meadow, Yosemite National Park. Photo by Jutta Schmidt-Gengenbach.

vegetation, playing a significant role in decomposition through soil perturbation.

Recent work by Holmquist and Schmidt-Gengenbach (Holmquist and Schmidt-Gengenbach 2006) in Sierra Nevada Network parks demonstrates the importance of wetlands as breeding grounds for invertebrates, which form the energetic basis of many food chains. Many insects breed in wetlands, and disperse into adjacent forests and woodlands as the season progresses.

Invertebrates also serve as pollinators for montane and high elevation plants.

We present an individual invertebrate conceptual model below (narrative and diagram, Figure F-19).

Stressors

Wetlands are susceptible to the same stressors that affect the Sierran parks as a whole. Climate change has the potential to shift the species composition of mountain wetlands through changes in the timing and amount of snowmelt and subsequent alteration of the underlying hydrology of local systems. Experimental manipulations in the Rocky Mountains demonstrate that increased temperatures can lead to a general drying down of mountain wetlands with subsequent invasion by woody species such as sagebrush, influence carbon fluxes (Saleska et al. 1999), and cause shifts in timing of flowering of wetland species (Dunne et al. 2003).

Although Sierran high elevation wetlands have so far proven to be relatively resistant to invasion by non-native plants (Gerlach et al. 2003b), wetlands in the lower montane are demonstrably susceptible to invasion by the non-native Kentucky blue grass (*Poa pratensis*),

which now dominates some heavily grazed wetlands (e.g., wet meadows) in Sequoia and Kings Canyon National Parks (Neuman 1990, Gerlach et al. 2003). Dandelion (*Taraxacum officinale*), a common invader of mountain wetlands worldwide, is also frequently encountered in disturbed wetlands and riparian areas of the Sierra, especially in those that are heavily grazed. Velvet grass (*Holcus lanatus*), Himalayan blackberry (*Rubus discolor*), and Bull thistle (*Cirsium vulgare*) are found in wet meadows in Yosemite Valley, Wawona, and elsewhere in the Park.

Nitrogen pollution from atmospheric deposition has the potential to affect productivity and species

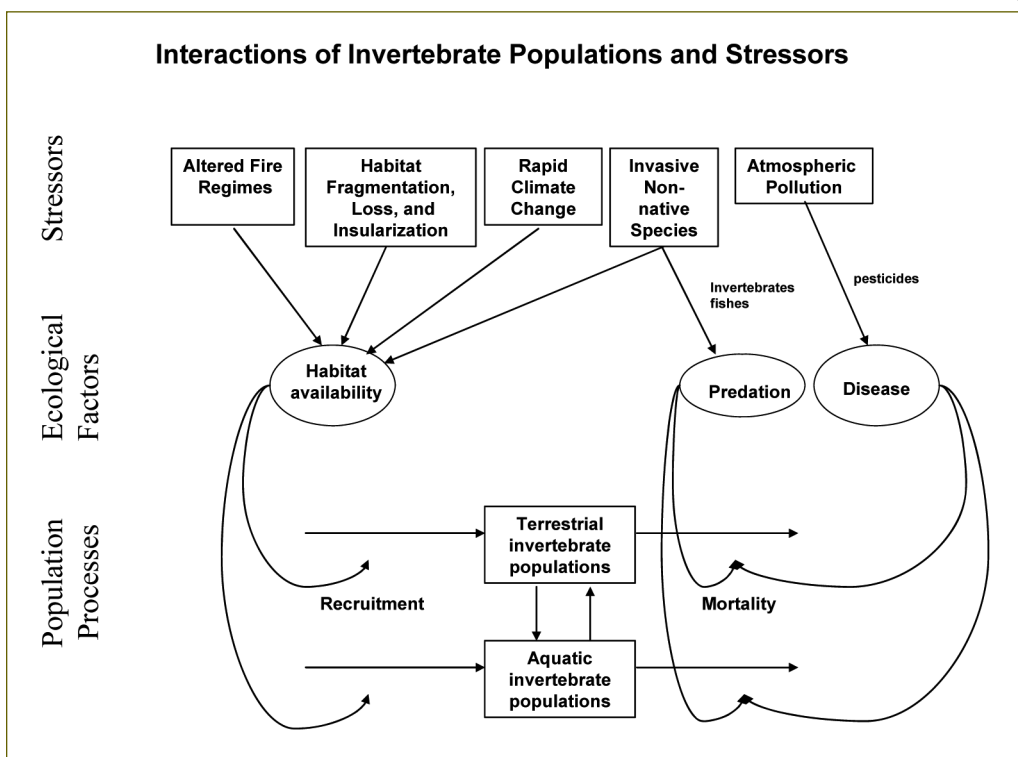


Figure F-19. Main interactions of invertebrate populations and stressors.

composition of wetland vegetation, and depending on seasonal timing, may affect aquatic organisms such as algae and microbes (see “Nitrogen Model,” *infra*). Affects to the primary producers of the aquatic food chain has the potential to significantly alter all wetland biota. Atmospheric deposition of pesticide contaminants has the potential to adversely impact aquatic biota through estrogenic effects from low concentrations, and also bioaccumulation.

Although fire can impact wetlands directly when vegetation is dry enough to burn, such events do not appear to lead to long-term changes (DeBenedetti and Parsons 1984). More long-lasting impacts are seen when in adjacent forests—specifically stand-removing fires, as a result of altered fire regime—are followed by increased flooding and surface erosion. This can lead to the deposition of sands and gravels during storm events and thus return the wetland vegetation to an earlier successional stage.

During the mid-1800s and into the early 1900s, most Sierran wetlands were grazed, in some cases severely, by cattle and sheep. Many park wetlands continue to be grazed by recreational pack stock, and this activity has a suite of known impacts to wetlands such as soil compaction, erosion, trampling of vegetation, and changes in plant species composition (McClaren and Cole 1993). Recent research in Yosemite National Park suggests that even moderate levels of such grazing can have a measurable effect on wetland productivity (Cole et al. 2004).

Wetlands have historically been manipulated in high use areas of Sierra Nevada network parks. Multiple direct anthropogenic impacts are a stressor of Sierra Nevada wetlands. Wetlands have been drained to provide parking, had flow modified to allow roads and trails to bisect them, had inundation levels altered by extraction of water from wells, and have been degraded by trampling from heavy use.

Vital Signs

Wetlands concentrate resources, provide critical habitat for both resident

and transient animals, are extremely productive, and have therefore been identified as key ecosystem elements in Sierra Nevada Network parks.

Our Wetland Ecological Integrity monitoring protocol targets the Network population of wet meadows and fens (see Appendix H, “Protocol Development Summaries”). This protocol will integrate monitoring of three indicators (i.e., vital signs): wetland plant communities (including vascular and non-vascular plants), and wetland water dynamics (groundwater and surface water), and wetland invertebrates.

Sub-Model: Invertebrates

Introduction

(Coleman and Hendrix 2000)) argue persuasively that invertebrates are “webmasters” that govern ecosystem function to a degree far out of proportion to their biomass. They form the energetic basis of many food chains (Figure F–19).

Drivers, Functions

Invertebrates are critical in decomposition, nutrient cycling, physical processes, and disturbance regimes (Meffe and Carroll 1997). As an example, soil invertebrates modulate the following, to varying degrees: soil temperature, moisture, nutrients, plant species composition, soil compaction, mixing, trace gas production, aggregate formation and stability, soil crusting, aeration, runoff, carbon storage, organic matter stabilization, macropores, water transport, and microbial community structure (Anderson 2000, Whitford 2000).

For example, ants can be considered keystone species in seasonally dry ecosystems because of their role in macropore formation alone (Whitford 2000). Insects are also important ecosystem regulators via the action of many species as powerful herbivores. The strength of this regulation is a function of small size, easily amplified biomass via short time to first reproduction, sensitivity to ecosystem condition communicated via airborne chemicals, diversity of niches occupied, and direct and indirect effects on primary production (Schowalter 2000).



Giant sequoia–mixed conifer forest. NPS photo.

Alpine wetlands are a particularly active arena for mobile, trophic-link organisms. Wetland invertebrates are tightly bound to neighboring streams, lakes, ponds, and upland habitats. Many aquatic larvae emerge from streams and ponds to spend their adult lives in wetlands before returning to the water to deposit eggs; examples include beetles, Diptera, mayflies, stoneflies, and caddisflies (Arnett 2000). Many organisms that are aquatic as larvae, are important pollinators in wetlands; these species are also important prey for vertebrates (e.g., amphibians, birds) in these habitats.

Recent work by Holmquist and Schmidt-Gengenbach in Sierra Nevada Network parks (Holmquist and Schmidt-Gengenbach 2006) demonstrated the importance of wetlands as breeding grounds for invertebrates, which form the energetic basis of many food chains. Many insects breed in wetlands, their offspring dispersing into adjacent upland forests and woodlands as the season progresses. Invertebrates also serve as pollinators for montane and high elevation plants. Wetland invertebrates are especially sensitive to fragmentation by trail corridors, with declines in species abundance and diversity observed as much as 2 meters away from trail beds in seemingly undisturbed vegetation (Holmquist and Schmidt-Gengenbach 2004).

Stressors

Invertebrates are particularly sensitive to disturbance—and some are exquisitely sensitive—because most of these organisms can emigrate as well as suffer mortality in situ. Because of generally limited dispersal capabilities and/or behavior, even comparatively mobile fauna may be influenced by climate change. Species with narrow temperature tolerances, such as alpine wetland grasshoppers ((Coxwell and Bock 1995), are likely to be affected strongly by climate change. In addition, effects are often amplified by rapid reproduction or lack thereof. However, disturbance will often increase diversity in invertebrate assemblages if disturbance levels are similar to, or lower than, natural rates of disturbance (Brown 1997).

Model: Forest System

Introduction

Sierra Nevada montane and subalpine coniferous forests comprise one of the largest and most economically, ecologically important vegetation regions in California (Rundel et al. 1988). This expanse includes most of the area of both slopes of the Sierra Nevada, from 600–1500 m at its lower margin, to 3000–3500 m at its upper limit (Rundel et al. 1988).

At the lower elevation range, montane conifer forests are characterized by ponderosa pine, incense-cedar, white fir, sugar pine, and black oak. More xeric sites are characterized by ponderosa pine-mixed conifer forests, while white fir-mixed conifer forests—with scattered giant sequoia groves—are found on more mesic sites. Above this zone—forming a transition to higher subalpine forests—occur upper montane red fir, Jeffrey pine, and lodgepole pine forests. The subalpine zone includes several geographically restricted forest types—this zone is dominated by mountain hemlock, western white pine, whitebark pine, foxtail pine, limber pine, and western juniper (Rundel et al. 1988).

Drivers, System Components, Function

Forest dynamics—primarily birth, growth, and death rates of trees—are sensitive to

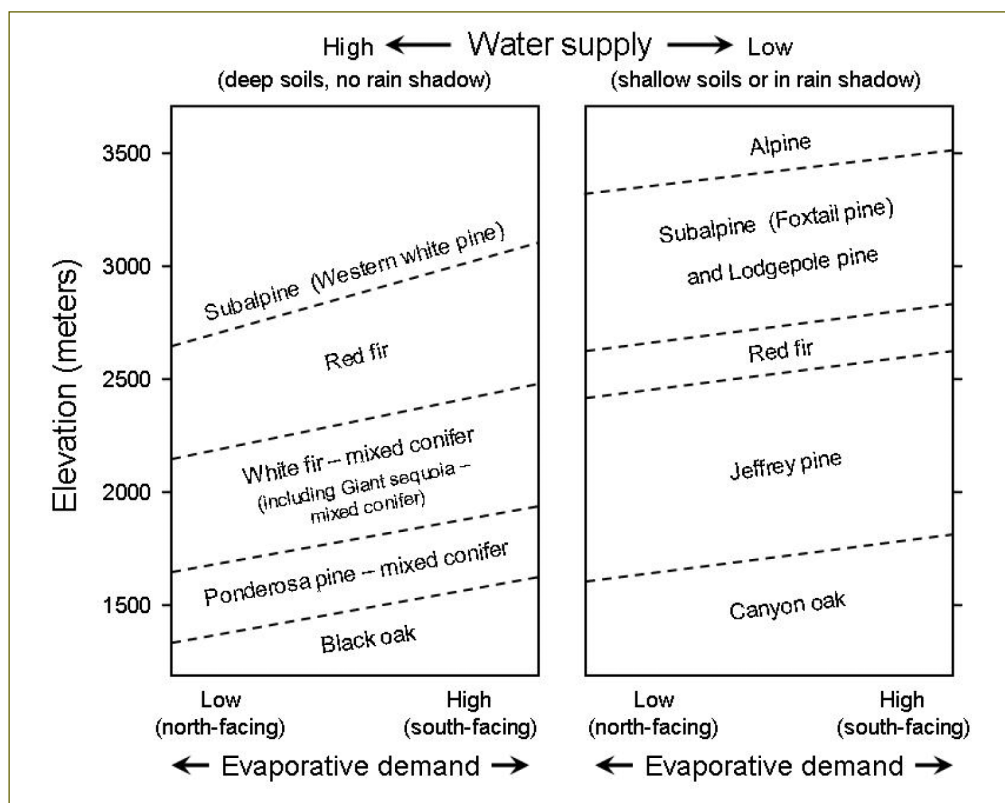


Figure F-20. The approximate distribution of forest types in southern Sierra Nevada relative to elevation, evaporative demand, and water supply. Only upland forest types (away from open water and wetland edges) are shown. Forest types intergrade extensively; boundaries between types are not sharply defined. In particular, intergradations between foxtail pines and lodgepole pines is so extensive that no boundary between the two types is shown. Because deep soils able to retain abundant water generally disappear at high elevations, no upper treeline is indicated in the high water supply diagram (on left). Modified from Stephenson (1988).

climate and fire regimes. Subsequently, human alteration of these regimes can stress forest ecosystems.

Sierra Nevada forest ecosystems are very complex in composition, structure, and function (Franklin and Fites-Kaufmann 1996). Forest distributions are linked to moisture availability, as determined by geology and topography, soil depth, and evaporative demand (Figure F- 20). Moisture availability affects growth, recruitment and death rates of trees, as well as frequency and intensity of fire.

The steep elevation gradient in the Sierra Nevada has a strong influence on vegetation, climate, and fire patterns. In the conifer zone of the central and southern Sierra Nevada, most (approximately 95%) precipitation falls from October through May. Thus, the amount of snowpack is much more important than rain in determining soil

water availability through the growing season. In our white fir-mixed conifer forests, moisture is more limiting to tree growth than temperature, because soil moisture usually declines throughout summer and into fall (while temperatures are still optimal for growth). High soil moisture availability in well-drained soils is believed to be the primary factor allowing giant sequoia to grow within present grove boundaries, but not in adjacent mixed-conifer forest (Rundel 1969, 1972). Thus, undisturbed grove hydrology is critical to giant sequoia ecosystem sustainability (Stephenson 1996). In addition to elevation, slope, aspect, and soil depth are also important to forest distribution, as explained by differences in water balance on north versus south slopes, and in deep versus shallow soils (Stephenson 1998).

Elevation is inversely related to fire

frequency (Caprio and Swetnam 1995, Caprio and Lineback 1997), and aspect differences result in different fire frequencies within the same elevations in a watershed (Caprio 2000). More mesic conditions on north slopes result in higher fuel moisture, and thus fires on these slopes tend to occur and spread mostly in drier years, compared to south slopes at similar elevations.

Vertebrates that live in white fir-mixed conifer forests do not, at larger scales, have substantial influence on population dynamics of trees. Animal (deer, small mammal) browsing of foliage may have small, localized effects on tree reproduction and vigor. Squirrels and chipmunks feed on conifer seeds, with large pine seeds (sugar pine, ponderosa pine, Jeffrey pine) being the preferred type of food, and white fir and red fir seeds preferred over the very small incense-cedar and giant sequoia seeds (Harvey et al. 1980). Douglas squirrels (*Tamiasciurus douglasi*) harvest green giant sequoia cones as well as seeds from other conifer cones for food (Harvey et al. 1980). At local scales, and in low seed production years, rodents may have some influence on seed availability and regeneration success. These species, including birds, do influence forest regeneration through the dispersal of seeds. Clark's Nutcrackers form a tight alliance with the subalpine white pine, although they are also known to descend into the upper montane to harvest fir seeds during the fall.

Our Network has tentatively identified several forest types for potential long-term monitoring (see Appendix H, "Protocol Development Summaries"). As an example of a forest system, we present a model of white fir-mixed conifer forest to highlight important ecosystem features, processes, and stressors that influence vegetation structure and composition in this forest type (Figure F-21). Population dynamics (seed fall, germination, recruitment, growth, and mortality) are highlighted.

Models for lower, and higher, elevation forest types will be similar, yet with different influences from fire, climate, insects/disease, invasive non-native

species, management action, and land use as agents of change affecting forest population dynamics, structure, and composition.

Stressors

Climate Change, Air Pollution

Stressors on forest dynamics that can be categorized under physical environment include anthropogenic climate change and air pollution. Climatic change may alter forest dynamics directly by affecting growth, mortality and recruitment rates of trees. Reduced water availability may increase frequency of drought events. The effects of drought on various life cycle stages of trees are likely to be more acute when accompanied by other stressors such as air pollution and fire exclusion (Savage 1994). Research and observation suggest that summer-time desiccation is the main cause of death of giant sequoia seedlings (Harvey et al. 1980, Stephenson 1994), thus warmer, drier summers could reduce recruitment of giant sequoias and other conifer species. A long time period of warming and/or drying could result in actual shifts in tree species distributions upward in elevation.

Recent research results suggest that forest dynamics may already be showing effects of climatic changes. Forest turnover rates (defined as the average of tree mortality and recruitment rates) have been increasing in tropical Amazonia (Phillips et al. 2004) and in the Sierra Nevada (Stephenson and van Mantgem 2005). In the Sierra Nevada, a possible cause for this rapid forest turnover rate is that summers have been getting warmer and drier. Snowpack has been decreasing over most of the West in recent decades (Mote et al. 2005), and spring stream flow has been occurring earlier (Stewart et al. 2004); see Stressor Model, and Atmospheric and Hydrologic System Models.

High levels of ozone in the southern Sierra Nevada are known to produce foliar injury and premature needle abscission (Duriscoe and Stolte 1989, Miller et al. 1991) and growth reduction (Peterson et al. 1987) in ponderosa and Jeffrey pines. Ozone also affects photosynthetic rates and stomatal

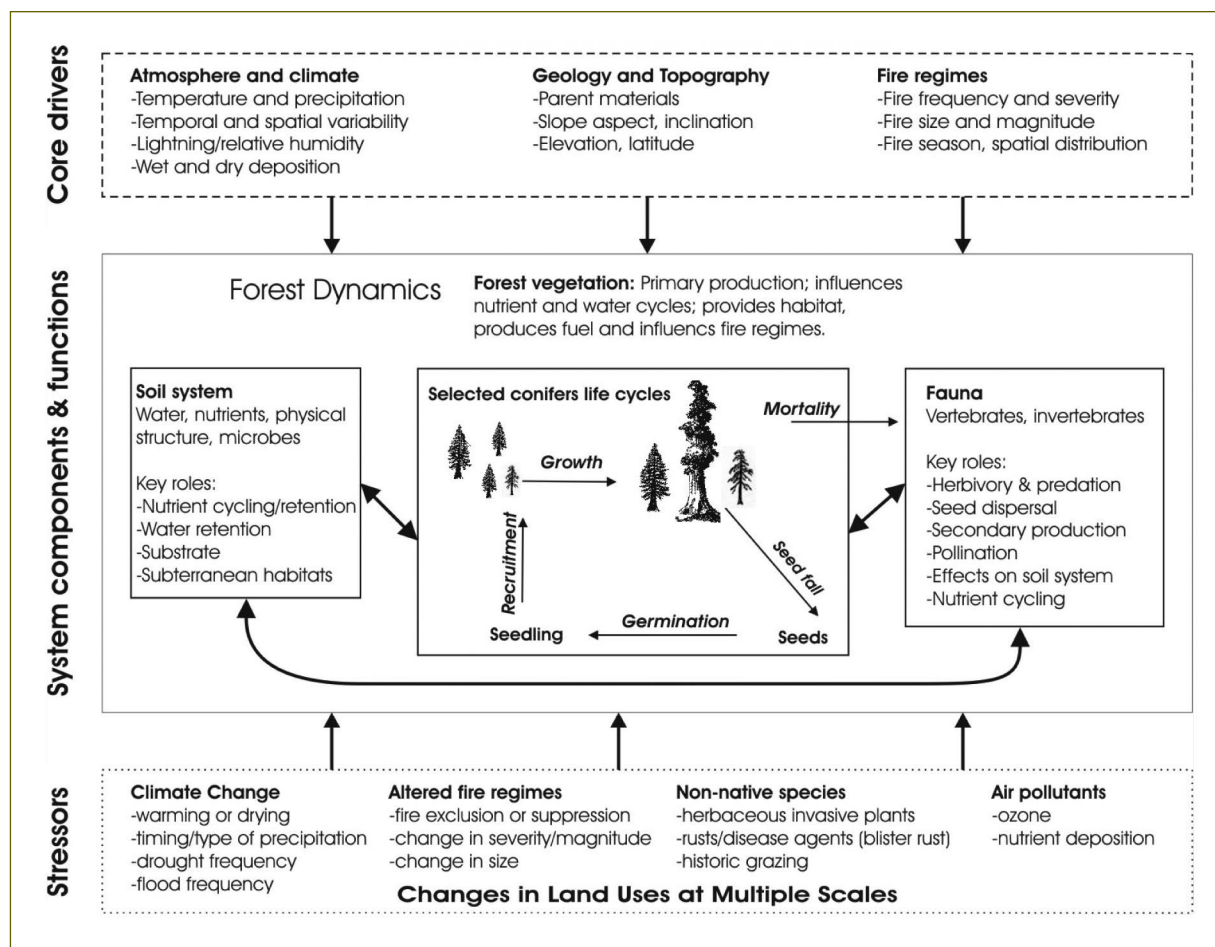


Figure F-21. White Fir–Mixed Conifer Forest Model, adapted from Vankat (Vankat 2004), to emphasize forest population dynamics). Rectangles=biotic components.

conductance in Jeffrey pine (Patterson and Rundel 1989). Giant sequoia seedlings were also demonstrated to have sensitivity (chlorotic mottle and leaf necrosis) to present ambient ozone levels and to 1.5X ambient ozone levels in fumigation experiments (Miller et al. 1992). Ozone injury can lead to reduced root development in sequoia seedlings, and this could prevent seedlings from being able to reach adequate subsoil moisture, critical to their survival in the first season of growth (Miller et al. 1992). In many cases, pollution weakens trees without being a direct cause of death (Savage 1994). Ozone damage may weaken trees' resistance to disease and insect attack.

Disease

A variety of native insects, rusts, fungi, cankers, and parasitic plants are associated with tree disease and death. Sierra Nevada

forest demography research has identified dwarf mistletoe (*Arceuthobium* spp.), fir canker (*Cytospora abietis*), and fir engraver (*Scolytus ventralis*) as commonly associated with mortality in fir species, and pine beetles (*Dendroctonus* spp.) as commonly associated with pine mortality (Parsons et al. 1992, Mutch and Parsons 1998). Occasional outbreaks of Douglas-Fir tussock moth (*Orgyia pseudotsugata*) occur, causing defoliation and mortality primarily in white fir. The nonnative white pine blister rust (*Cronartium ribicola*) is an important factor associated with 5-needle pine mortality in the Sierra Nevada (Duriscoe and Duriscoe 2002) and elsewhere. Over the past 15 years, sugar pine deaths in Sequoia National Park associated with blister rust and stress (i.e., resource competition) were common, suggesting significant roles for both blister rust and fire exclusion in population trajectories (van Mantgem et al. 2004).

Non-native Plants

Non-native plants do not currently represent a major problem in Sierra Nevada parks' white fir-mixed conifer forests. The return of fire through prescribed burning, and allowing lightning-caused fires to burn, has increased species richness in this montane forest type (Keeley et al. 2003). However, increased gap formation from fire also increases potential for invasions of alien plants (Hobbs and Huenneke 1992, Keeley et al. 2003). In Sequoia and Kings Canyon National Parks, Keeley et al. (2003) found that aliens comprised only 0.3% of understory flora in unburned forests (unburned for at least 75 years) and 3.4% in burned forests. Disturbances created by timber harvest may result in many times greater alien composition (Battles et al. 2001). The invasive problem in central and southern Sierra Nevada forests centers primarily around cheatgrass (*Bromus tectorum*). *Bromus tectorum* has had drastic effects on fire regimes throughout the Great Basin (Mack 1981, Whisenant 1989), and there is concern that it could alter fire regimes in the Sierra Nevada as well (Keeley 2001). It is through altering fire regimes that invasive species are likely to have the most impact on montane forests. Other alien invasive species most commonly associated with burned areas in network white fir-mixed conifer forests include: bull thistle (*Cirsium vulgare*) and wooly mullein (*Verbascum thapsus*) (Demetry, pers. comm.).

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Fire Regime

Please refer to detailed "Fire Regime Model" (below).

Vital Sign

The Sierra Nevada Network has identified several forest types for potential long-term monitoring; final selection will occur during Forest Monitoring Protocol development (see Appendix H, "Protocol Development Summaries").

We are interested in monitoring forest dynamics, and primarily—birth, growth and death rates of trees, because they are sensitive to changes in two major drivers in the Sierra Nevada: climate and fire regimes. These two drivers are subject to substantial alteration by human impacts, and in these altered states can act as stressors on forest systems.



Prescribed fire in giant sequoia-mixed conifer forest. NPS photo.

Monitoring recruitment, growth, and mortality rates, along with causes of tree death, provides simple and well-understood metrics for quantifying and interpreting changes in forest tree populations in response to climate, fire, and other agents of change (e.g. insects, pathogens).

Monitoring of forest dynamics will need to be linked to monitoring of fire regime, fire effects, and climate to enable effective interpretation of trends in tree population dynamics and large-scale forest landscape changes in pattern and structure.

Model: Fire Regimes

Text Adapted from Caprio (Caprio 2003)

Introduction

Fire is a process that helps link terrestrial, atmospheric, and aquatic systems through its role in moving nutrients across these systems. Fire regimes—in combination with climate and topography—shape vegetation structure and pattern on the landscape, affect water quality and quantity, and indirectly affect wildlife habitat.

The importance of fire as a key driver and process in Sierra Nevada ecosystems was discussed in “Forest System” and “Stressor” model, supra, and Chapter 1. Here, we elaborate and emphasize linkages between fire and climate and their roles in influencing vegetation pattern and various ecosystem processes.

Climate—A Driver & Stressor

Climate primarily affects fire regime through its direct effect on fuel moisture. A short period of dry, hot weather can severely dry fuels, often overwhelming any effects that might be due to fuel loads or fuel bed structure. Climate also affects the geographic distribution of vegetation types and site productivity, and, thus, indirectly influences the intensity, frequency, and size of fires (Miller and Urban 1999c). Fire frequency tends to decrease with increasing elevation and soil moisture (Figure F- 22), interacting with topographic moisture gradients and fuel availability to help shape vegetation distribution and landscape pattern. Over longer time scales, climatic fluctuations are responsible for driving variations in

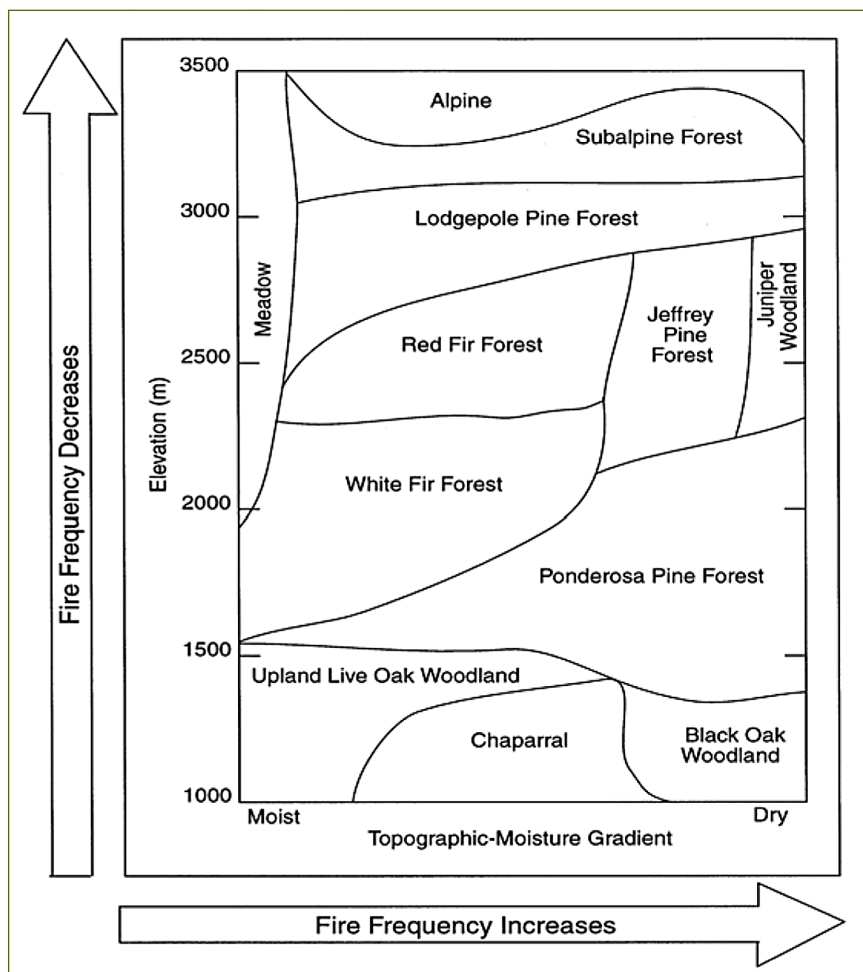


Figure F-22. The distribution of general vegetation types (Vankat 1982) and the relation of fire frequency to elevation, topographic, and moisture gradients in Sequoia National Park (Miller and Urban 1999c).

fire regimes (Clark 1988, Swetnam 1993a).

Attributes of pre-Euroamerican fire regimes can provide vital reference information for understanding changes in ecosystems over the last 150 years and in developing goals for the restoration of fire. The concept of a fire regime allows us to view fire as a multifaceted variable rather than a single event within an ecosystem (Whelan 1995). Thus areas can be classified as having a certain type of regime that summarizes the characteristics of fires, within some range of variability having both spatial and temporal attributes. Fire regimes are normally defined according to specific variables, including: (1) frequency, (2) magnitude (intensity, severity), (3) size, (4) season, (5) spatial distribution, and (6) type of fire (Gill 1975, Heinselman 1981). Fire regime characteristics may vary through time, and across the landscape,

in response to climatic variation, number of lightning ignitions, topography, vegetation, specific historic events, and human cultural practices (SNEP 1996).

A graphic overview of fire regime attributes and affected ecosystem properties is provided in Figure F-23. Fire regimes are also tightly linked to climatic variation (Swetnam 1993b). Predictions for increased fire severity and size in the Sierra Nevada with global warming (Torn and Fried 1992, Miller and Urban 1999a) suggest that monitoring fire regimes and their effects on the ecosystem will be essential in enabling managers to adapt to, and mitigate for, changing conditions.

Stressors

Altered Fire Regime—A Stressor

As discussed earlier (see “Forest System Model”, Figure F-21), altered fire regime is itself a stressor to Sierra Nevada ecosystems. Beginning in the 1860s, fire

regime abruptly changed when human ignitions decreased (concomitant with decline of Native American populations), and cattle and sheep grazing reduced fuel loads (Parsons 1981, Swetnam 1993) (Vankat 1977). With the establishment of Sierra Nevada national parks in the late 19th and early 20th centuries, aggressive suppression of wildfires was initiated (Vankat 1977). In some forests, a pulse of tree reproduction followed the end of grazing: (1) seedlings became established in grazing-disturbed areas; (2) domestic animals no longer trampled or ate seedlings; and (3) fires were suppressed (Vankat and Major 1978).

Sierra Nevada montane forests are highly dependent on fire. Detailed fire histories obtained from fire scar sampling on tree trunks, logs, and snags (in white fir- and giant sequoia-) mixed conifer forests, demonstrate that fire return intervals in these forests prior to the mid 1860s ranged from 1 to 30 years, with the mean

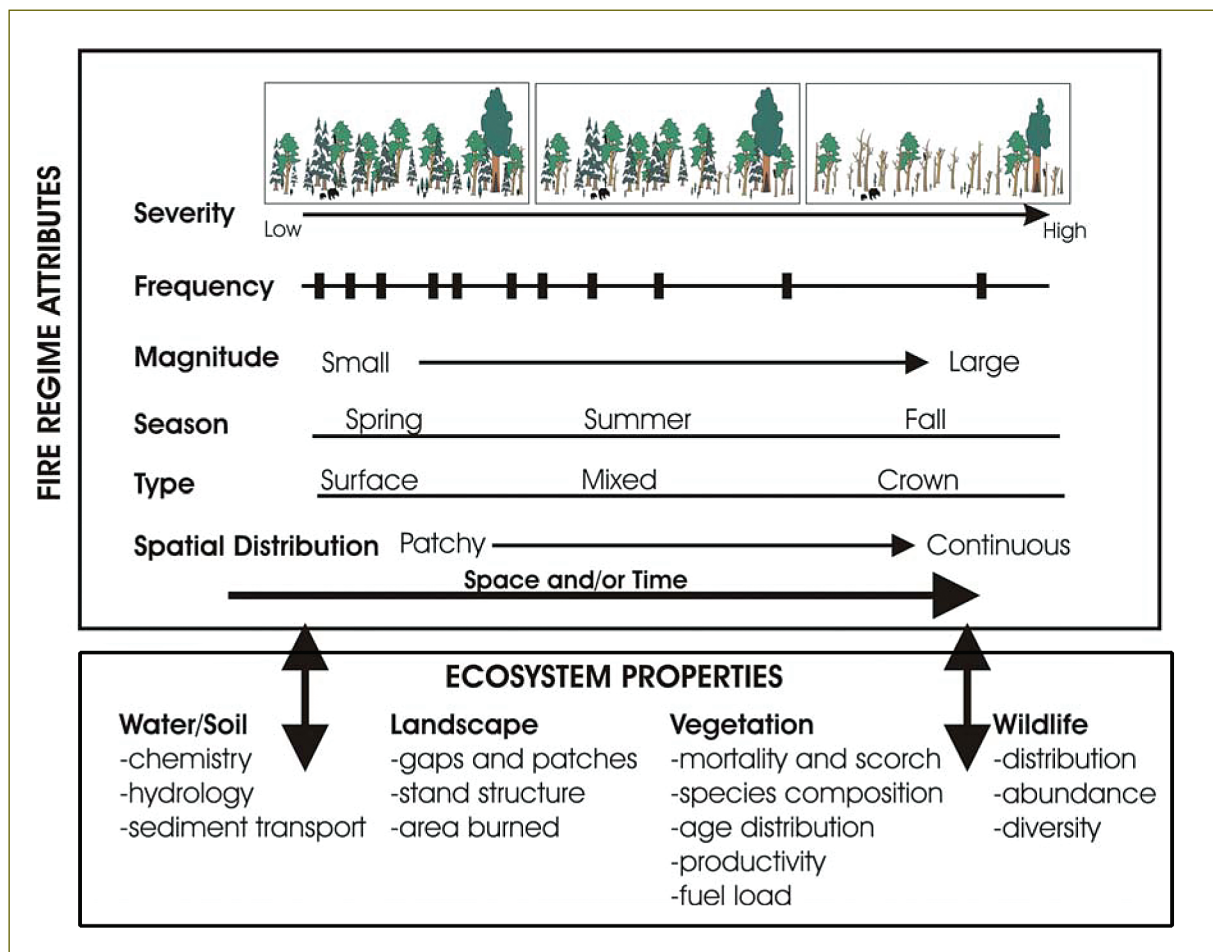


Figure F-23. Fire regime attributes and selected ecosystem properties influenced by fire (described in model narrative).

fire interval ranging from 10 years to a more conservative maximum mean of 16 years (Kilgore and Taylor 1979, Swetnam et al. 1992, Swetnam 1993, Caprio and Swetnam 1995, Swetnam et al. 1998, National Park Service 2003a).

A variety of studies suggest that past Sierran mixed conifer forests had lower tree density, and a very different demographic distribution of age classes—with lower fuel loads and greater landscape diversity of forest patches than current forests (Parsons and DeBenedetti 1979, Bonnicksen and Stone 1982, Vale 1987, Ansley and Battles 1998, Roy and Vankat 1999, Stephenson 1999)((Vankat and Major 1978). While many of the changes observed in forest structure and function are thought to primarily be a result of fire exclusion, they may also be related to warmer, moister conditions of the 20th century (Graumlich 1993, Scuderi 1993, Keeley and Stephenson 2000).

While the type of fire regime in white fir-mixed conifer forests (inclusive of giant sequoia groves) is often described as understory or low intensity surface fires, there is evidence from studies of forest age structure and post-fire giant sequoia growth response that low intensity fire interspersed with patchy high intensity fire is needed for successful recruitment of shade-intolerant giant sequoias seedlings (Harvey et al. 1980, Harvey and Shellhammer 1991, Stephenson et al. 1991b, Stephenson 1994, Mutch and Swetnam 1995). Stephenson (1994) estimates that a minimum of 0.1 ha gap size is needed for significant giant sequoia recruitment. In addition to favoring seedling establishment, patches of higher intensity fire result in release of more seeds from semi-serotinous giant sequoia cones. Other canopy dominants (sugar pine, Jeffrey pine) are dependent on gaps for effective regeneration, and the distribution of forest gap generated patches also likely has important effects on the distribution of wildlife (Keeley and Stephenson 2000). In general, a higher diversity of species composition, forest size structure, and landscape pattern occurs with a natural stand-thinning fire regime (Figure F–24).

Establishment of prescribed fire programs in Sierra Nevada parks in the 1960s resulted in substantial progress toward reducing fuel loads, and modifying stand structure to reduce tree densities in many areas (Kilgore 1973, Keifer et al. 1995, Keifer et al. 2000).

Lightning-caused fires cannot always be allowed to burn due to constraints of development, air quality restrictions, proximity of neighboring lands with commercial timber, human-made barriers to fire spread, and staffing restrictions during busy fire seasons. Thus management-ignited fires will need to continue to play a significant role in restoring historic fire regimes to park landscapes (Keeley and Stephenson 2000).

See also, “Stressor Model,” for a discussion of the effect of altered fire regime on vegetation and other ecosystem attributes.

Fire and Nutrients

Several Sierra Nevada studies have documented increases in stream solute concentrations after fire (Chorover et al. 1994, Williams and Melack 1997a, b, Heard 2005), probably due to increased runoff, changes in biogeochemical processes, and direct deposition of ash into waterbodies. Burning and decomposition of plant material, accelerated mineralization and erosion rates, and decreased nutrient uptake by vegetation also lead to increases in solute concentrations in soil solution (Raison 1979, DeBano et al. 1998). While many elements, particularly nitrogen, sulfur, and carbon, are converted to volatile compounds and ascend to the atmosphere (Covington and Sackett 1984, Caldwell et al. 2002), high concentrations of these elements are also left behind in ash layers and partially combusted organic material (Blank and Zamudio 1998). Fire may accelerate some losses of nutrients through combustion and leaching, but it also plays a critical role in supplying available nutrients to terrestrial and aquatic systems (St. John and Rundel 1976, Romme and Knight 1982, Hauer and Spencer 1998). Fire releases nutrients bound in above-ground organic matter, rendering them available in organic forms for plant and microbial uptake.

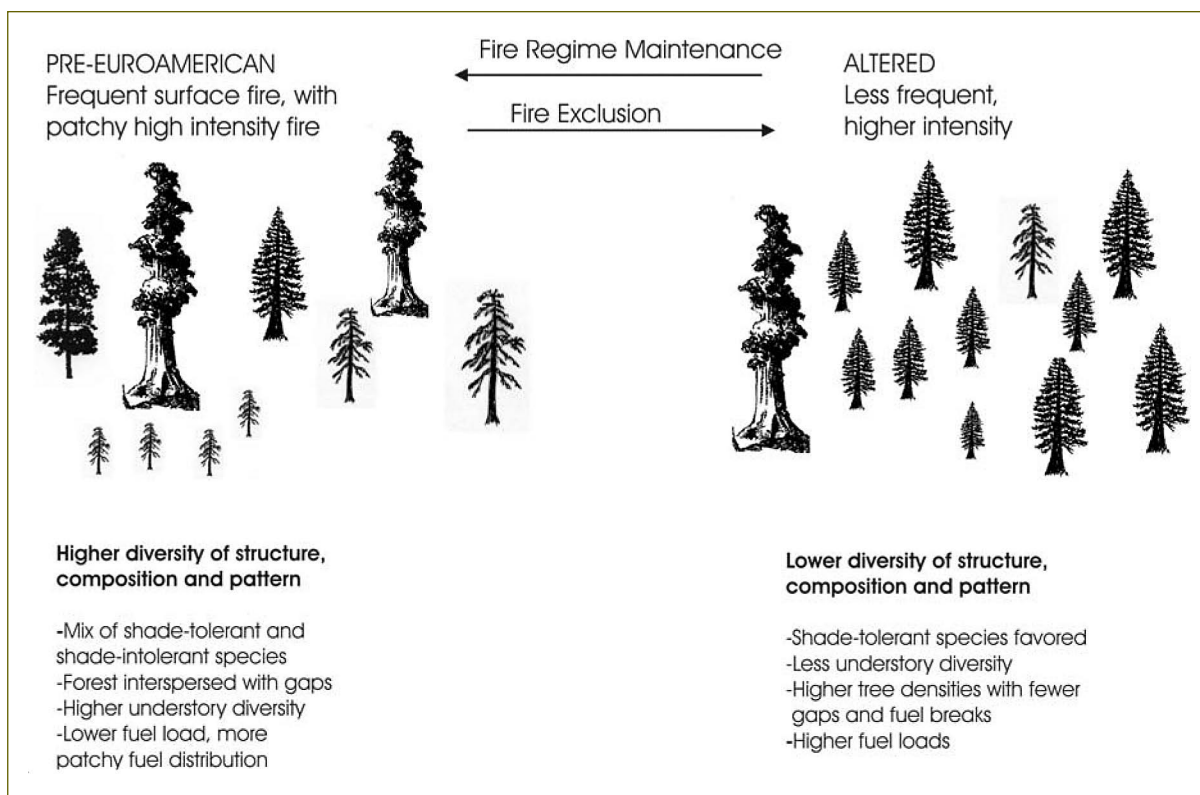


Figure F-24. Fire regime effects on white fir-mixed conifer forest structure, composition and pattern. Alteration of the fire regime, through fire exclusion, results in the types of changes indicated above for Sierra mixed conifer forests.

Fire Regime Attributes

Fire Frequency

Fire frequency is usually defined as the number of fires per unit time, or mean fire return interval (mean number of years between fires). General patterns of pre-Euroamerican fire frequencies are apparent at several scales within our parks. Variation exists locally, with specific site characteristics such as productivity, potential for ignition, or other factors influencing frequency. General patterns are also apparent at large scales. For example differences in fire frequency are observed in different vegetation types (Figure F- 25).

Additionally, on the west slope of the Sierra, frequencies (reconstructed using fire-scarred trees) show an inverse relationship between number of fires and elevation (Caprio and Swetnam 1995, Swetnam et al. 1998, Caprio 2000). Fire return intervals are longest at higher elevations, shortest in lower mixed conifer forest, and appear to again increase in time between fires in lower elevation grass-oak woodland

and chaparral vegetation (Caprio and Swetnam 1995, Caprio and Lineback 1997). Additionally, within at least some watersheds strong differences in fire frequency exist between aspects, with fire frequencies being shorter on south aspects than on north aspects (Kilgore and Taylor 1979, Caprio 2000).

Fire Magnitude

Fire magnitude characteristics, such as intensity and severity, also vary among vegetation types. Fire intensity is defined as the physical force (i.e., BTUs) of the fire per unit time (Pickett and White 1985). Severity refers to impact of the fire on organisms, communities, or ecosystems (e.g., basal area removed) (Sousa 1984, Pickett and White 1985). Fire severity is closely related to weather, fuel load, size and distribution of fuel and moisture content of fuel and soil (Wright and Bailey 1982). It is a common indicator of fire effects on vegetation. An inverse relationship is often observed between disturbance size and/or severity and disturbance frequency (Sousa 1984, Pickett and White 1985, Swetnam 1993).

At lower elevations, little is known about fire regimes in grasslands and oak woodlands due to (1) lack of fire scarred trees, and (2) replacement of nearly all native herbaceous communities by alien plants, following initiation of intense grazing in the 1860s (Dilsaver and Tweed 1991). However, descriptions of vegetation suggest that episodic fast-moving surface fires in flashy herbaceous fuels, during dry summer and fall seasons, probably played a role in these communities (Parsons 1981). Stand-replacing fire in chaparral communities today probably differs little from pre-Euroamerican characteristics, although frequencies have probably been altered. In much of the Sierra's sequoia-mixed conifer forest, fires were primarily non-stand replacing surface fires prior to Euroamerican settlement (Show and Kotok 1924, Kilgore and Taylor 1979, Warner 1980, Pitcher 1987, Caprio and Swetnam 1995). Fires in these areas were dominated by low to moderate severity, with high-severity generally restricted to localized areas (Stephenson et al. 1991). Fire in red fir forest was typically non-stand replacing, due to its fire resistant bark (Pitcher 1981, 1987). Fire in lodgepole pine was generally a patchwork

of low-intensity surface fire, and higher-intensity crown fire, depending on specific burning conditions.

Fire Size

The scale of fire prior to Euroamerican settlement was significantly different from that typically observed today. Both frequency of fire occurrence—and frequency of large spreading fire—was much greater than today or at any time in the last hundred years.

Estimates based on fire history data suggest that between 15,100 to 24,700 acres burned annually within the parks (Caprio and Graber 2000). However, because of the vagaries of climate or number of ignitions, actual number of acres burned in any given year could have been much greater, or smaller, than those averages.

Fire size was probably also related to overall landscape diversity patterns such as vegetation, fuel, and topographic complexity. In course-grained landscapes, such as the highly dissected, rocky, high country (upper Kern and Kings River drainages), fires probably tended to be smaller, with poor year-to-year synchrony. In contrast, fires were probably larger

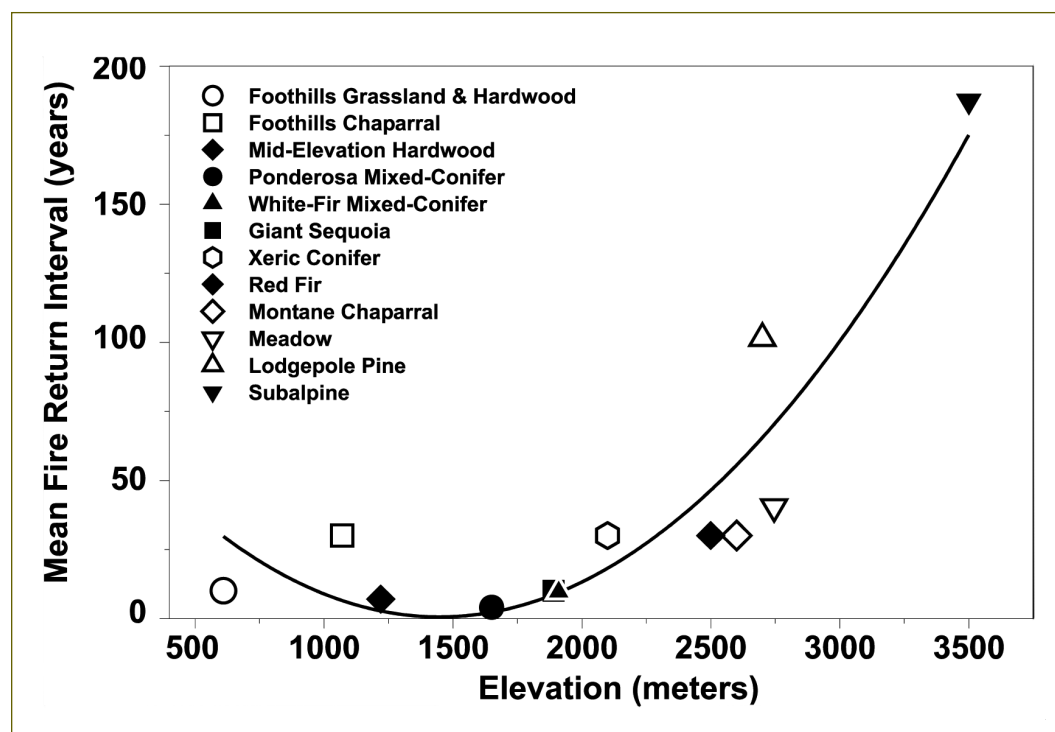


Figure F-25. Relationship between fire frequency and elevation, Sequoia and Kings Canyon National Parks (from Caprio and Lineback 1997).

and more synchronous in fine-grained watersheds, such as those found on the west side of the range. Burn patterns in these landscapes would be related to fire conductance among vegetation types and between drainages (Caprio 2003, National Park Service 2003a).

Season

Season of fire occurrence can have important effects on vegetation and wildlife. Factors important in seasonality are fuel moisture content, phenology of vegetation, and life history patterns of wildlife. Vegetation and wildlife within particular ecosystems have generally adapted to fire within a particular window of time. However, changes in seasonality, outside the normal range of variability, may have adverse impacts. In the Sierra Nevada, pre-Euroamerican settlement fires generally occurred from summer through fall, based on analysis of seasonal positions of fire scars in tree rings (Swetnam et al. 1992, Caprio and Swetnam 1995). This is in agreement with current knowledge of contemporary lightning ignition and fire spread patterns (Show and Kotok 1924, Vankat 1985), Sequoia Kings Canyon and Yosemite fire records).

Fire Type

Fire regime types range from no fire, to surface fires and crown fires, all with various combinations of fire types related to vegetation, fuel characteristics, weather and topography. Common fire regime types for major SIEN park vegetation communities can be broadly defined as: (1) short-interval, low-intensity surface fires, (2) moderate interval, stand-replacing fires, (3) variable-interval, variable-intensity surface fires, (4) long-interval, low-intensity surface fires, (5) long-interval, high-intensity surface fires, (6) long-interval, variable intensity fires, and (7) lack of fire.

Spatial Distribution of Fire

The distribution of fire on the landscape at any given time is dependent upon many variables, including ignition source(s), topography, fuel continuity, structure and moisture; and weather conditions. Spatial distribution and pattern of fire are also dependent

upon fire frequency and longer-term climate patterns. High fire frequency periods probably had small patchy fires and resulted in a fine-grained pattern in vegetation and fuels, while low fire frequency periods had wider spreading fires resulting in coarser-grained landscape patterns (Swetnam 1993b). Fire and forest dynamics modeling efforts for Sierra Nevada have suggested fire can increase heterogeneity in some forest characteristics (variability in species composition) and alter spatial heterogeneity (light regime within forest more variable with fire) (Miller and Urban 1999b). Fire suppression has likely resulted in more homogeneous forests, from fuel accumulation and increased density of understory trees (Vankat and Major 1978), creating forests more susceptible to larger, more severe fires.

Potential Fire Regime Indicators

To monitor fire regimes as a process, landscape-scale monitoring of key attributes of fire regimes will be necessary. Fire severity, size, season and spatial distribution are all potential indicators that could be monitored using a combination of on-the-ground fire monitoring, remote-sensing, and GIS analysis. Some of these attributes are already being monitored in SIEN parks (National Park Service 2003a, 2004), and collaborative planning with park fire management will be needed to determine how our vital signs monitoring program can enhance and integrate with existing efforts. While the vital signs program does not propose to explicitly monitor fire effects on ecosystem properties, many of our selected vital signs (water chemistry, hydrology, forest stand population dynamics, bird populations) are affected by fire occurrence.

Vital Sign

Monitoring of forest dynamics will need to be linked to monitoring fire regime and fire effects to enable effective interpretation of trends in tree population dynamics and largescale forest landscape changes in pattern and structure.

While mid-elevation mixed conifer forests occupy a large area and contain

focal species of interest for long-term monitoring (giant sequoia, sugar pine, Jeffrey pine), other forests of interest include those at the lower and upper elevation ranges, as these are areas that most likely to be sensitive to climatic change. Low-elevation forests in the Sierra Nevada are the most dynamic (i.e., highest turnover rates), and therefore may respond most quickly to environmental change (Stephenson and van Mantgem 2005). High elevation forests may respond more slowly to a given unit or pace of climatic change. Model projections suggest that climate may change more rapidly at high elevations in the Sierra than at low elevations (Knowles et al. 2006). Monitoring tree population dynamics and forest density at, and near, treeline also offers an opportunity to detect the beginnings of an upward shift in a highly climate-determined ecotone.

Model: Non-native Invasive Plant Populations

Introduction

Invasive species have the ability to alter the local environment, perpetuating their own existence at the potential

expense of native species (Hobbs and Mooney 1998). The most destructive invasive plants can alter ecosystem processes, such as fire regimes (D'Antonio and Vitousek 1992, Brooks et al. 2004), nutrient cycling and soil chemistry (Ehrenfeld 2003), hydrological cycles (Blackburn et al. 1982), and sedimentation rates (Blackburn et al. 1982). In doing this, they have the potential to out-compete native species, lower native species recruitment, alter the community structure, and degrade or eliminate habitat for native animals (Bossard et al. 2000). Because of these effects (Figure F-26), and because of the number of extant taxa and populations, non-native invasive plants are one of the five major stressors affecting parks in the Sierra Nevada network.

Not all plant communities have been invaded by non-native plants. Furthermore, the qualities that make a plant community susceptible to colonization by non-native plants (i.e., invasibility) are not generally understood (Rejmanek and Richardson 1996)(see also Model: Invasive Plant-Susceptibility, below). The primary interest in

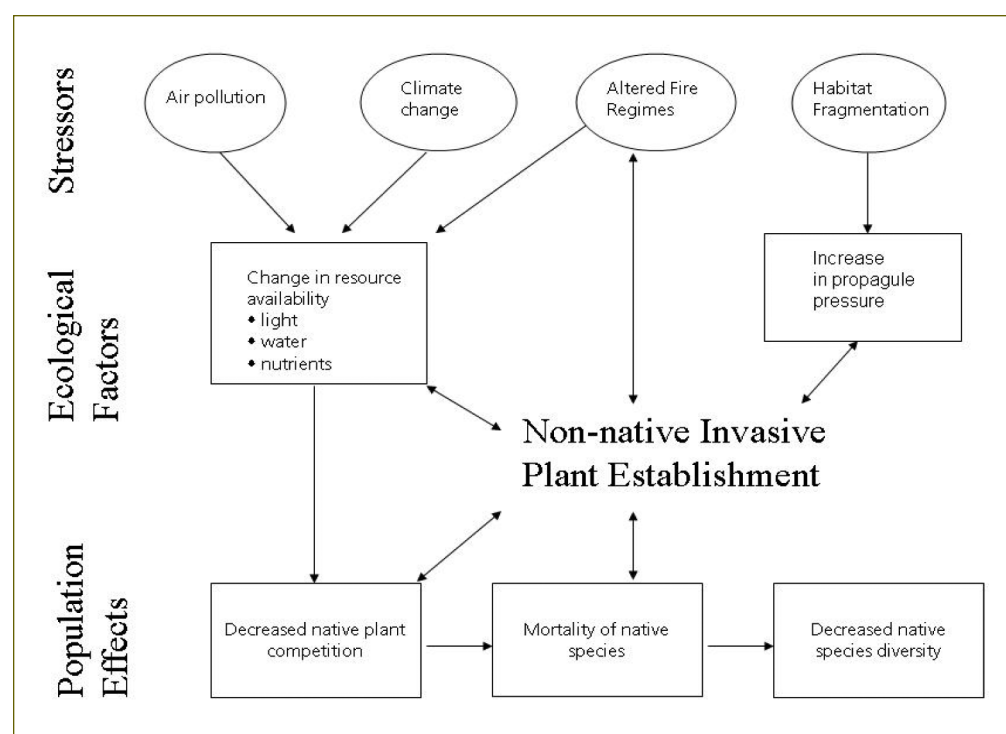


Figure F-26. Non-native Invasive Plant population conceptual diagram, depicting principle interactions of stressors and ecological factors.

monitoring nonnative invasive plants is to improve early detection of both new taxa that have not yet arrived in SIEN parks, and new populations of non-native species that already occur in parks.

Although there has been extensive research surrounding how and why exotic plants become invasive (Mack and D'Antonio 1998, Lonsdale 1999, Davis et al. 2000a), an all-encompassing theory on invasion has yet to be developed. Several models of community invasibility are presented below (see companion conceptual models).

Studies examining individual characteristics of invasive species are limited in their applicability to all invasive plants, as it is unlikely that there will ever be a set of characteristics inclusive to all invasive species. On the ecosystem level, however, theories have been more encompassing. Many studies agree that a change in resources, such as water, light and nutrients, is a major cause of invasive plant establishment in an ecosystem. The theory of fluctuating resources (Davis et al. 2000) provides one of the most widely accepted models (Richardson and Pysek 2006). This model states that when there is a change in the amounts of resources, even the slightest amount, invasives can have an opportunity to take over a niche and enter the ecosystem. These changes can occur when there is a disturbance, such as heavy herbivory, erosion, or soil degradation; an increase in precipitation (a wetter year than average); or a eutrophication event (Davis et al. 2000). In addition, the presence of invasives can alter environmental conditions, such as altering biogeochemistry, and cause changes in the ecosystem to become more favorable for self-maintenance. This theory is explained in detail, below; see Model: Non-native Plants—Invasion Susceptibility.

Introduction of species into SIEN parks depends in part on whether surrounding communities (proximity of source) have been invaded, and on the vectors available to transport the plant (or its propagules) into our parks. Natural transport vectors, such as wind and animals, can move propagules. Plants or propagules may also be transported by human activities that import

contaminated materials into the parks. These materials may include equipment, soil, sand, gravel, hay, straw, pack-stock dung, cultivated plants, car tires, and shoes. Once established inside parks, many of these same vectors can move the plants farther into the interior.

Status of Non-native Plants in Network Parks

Currently, there are over 260 non-native species documented for SIEN parks—all are non-native, but not necessarily invasive (depending on definition used):

- SEKI—215 species (100 of which do not occur in YOSE)
- YOSE—160 species (45 of which do not occur in SEKI)
- DEPO—8 species

Research has been conducted in the Sierra Nevada examining invasive species' dynamics. Studies have looked at relationships between invasive plants and human-disturbed areas (Moore and Gerlach 2001, Gerlach et al. 2003), riparian areas (Kane et al. 2006), burned areas (Keeley et al. 2003, Klinger et al. 2006, Kaczynski 2007), and grazed areas (Keeley et al. 2003). There have also been species-specific studies on *Cirsium vulgare* (Randall 1988) and *Bromus tectorum* (McGinnis and Keeley, unpublished). Our network contracted a study to model invasive species to predict where invasive species may be found—particularly those in naturally disturbed habitat—throughout the Sierra Nevada (Klinger and Underwood 2002, Underwood et al. 2004), the results of which were the impetus for the Kane et al. (Kane et al. 2006) and Kaczynski (Kaczynski 2007) studies listed above. Other studies have typically been sited in locations with anthropogenic disturbance, as humans are known to be important vectors for invasive plant dispersal (Gerlach et al. 2003). Elevation is known to have a strong effect on non-native invasive plant presence, with populations decreasing with increasing elevation.

A recent study modeling the relationship between non-native species and burned areas, examined various biotic and abiotic factors involved in non-native

species presence (Klinger et al. 2006). This study found that non-native species cover and richness were strongly positively correlated with slope and total herbaceous cover. Non-native invasive richness was strongly negatively correlated with elevation and cover of trees and shrubs. Invasive plants occurred more frequently than was expected in lower montane conifer plots (Klinger et al. 2006).

Stressors

Researchers have identified four major systematic stressors in the Sierra Nevada Network parks that could promote establishment of non-native invasive plants (SNEP 1996). These include: (1) climate change, (2) altered fire regimes, (3) air pollution, and (4) habitat fragmentation. Non-native species, themselves, are the fifth systemic stressor.

Climate change

Effects of climate change include changing temperatures and changing amounts of precipitation. These effects contribute to a change in the overall resources (specifically water and nutrients) that are present in the ecosystem (Davis et al. 2000a). Some studies have shown that even a short-term increase in the amount of water in a system can lead to the long-term establishment of non-native invasives, specifically grasses (Dukes and Mooney 1999). Non-native invasive plants have proved to be very adaptable to changes in the ecosystems. A possible reason for this being that many of the worst non-native invasives are found to have very large and variable geographic ranges (Richardson and Pysek 2006). This adaptability has been seen on a regional scale, where yellow star thistle populations in coastal areas of California are characteristically different from populations farther inland (Maddox and Mayfield 1985).

Altered Fire Regimes

Historically, the Sierra Nevada ecosystems have had variable temporal scales of fire. Within the past century, the overall management strategy has been fire exclusion and suppression. However, within the past 30 years, reintroduction

of fire has been a management goal within the SIEN parks. A dilemma exists with regards to the reintroduction of fire and its relationship with non-native invasive plants: allowing fire back into ecosystems may allow for more non-native invasives to establish, due to creating a site very conducive for establishment. It has been hypothesized that the altered fire regimes may have helped to keep non-native invasive populations low in certain ecosystems (Keeley 2001).

Due in part to the exclusion of fires, many of the mid-elevation conifer forests have been relatively free of non-native invasives. McGinnis and Keeley (unpublished) found that *Bromus tectorum* presence in *Pinus ponderosa* stands in Kings Canyon will be on a “boom and bust” cycle—when there is a fire that eliminates the litter layer, *B. tectorum* will establish, however when the litter layer builds up the *B. tectorum* can not survive. Populations of non-native invasives decrease as the years after the fire increase (Klinger et al. 2006). Recognizing that there is a relationship between non-native invasives and fire will assist managers in early detection of the species.

Air pollution

One consequence of air pollution is nitrogen deposition. Examining this in the context of the Davis et al. (2000) model, this increase can aid the establishment of non-native invasive plants. Increased levels of nitrogen favor faster-growing plants. Sierra Nevada has high rates of nitrogen deposition due to proximity to sources of high emissions and also an atmospheric inversion that occurs below an elevation of 1000 to 2000 meters (Fenn et al. 2003). The effects of increased CO₂ concentrations and non-native invasive plants are still debated. However, non-native invasives that utilize C₃ pathways for photosynthesis (see basic botany text) (ex. *B. tectorum*) have responded favorably to increased CO₂ concentrations. Non-native invasives that utilize C₄ and CAM pathways responded less predictably (Dukes and Mooney 1999). Increased CO₂ levels

do stimulate overall growth in all plants and as a result can increase fuel loading, leading to more frequent and severe fires (Dukes and Mooney 1999).

Habitat fragmentation

Anthropogenic effects within the parks (roads, corrals, campgrounds, trails) that fragment the landscape act as corridors for non-native invasive plants to travel farther into ecosystems. Gerlach et al. (2003) studied the presence of non-native invasives at these sites because randomly located sites across the landscape yielded few individuals. Habitat fragmentation surrounding the parks will also allow for the higher likelihood of invasion, due to an increase in propagule pressure.

Vital Sign

In addition to being a “vital sign”, as stated previously, non-native invasive plants are considered one of the five main stressors on SIEN park ecosystems. Their presence can have an effect on seven of the Network’s 13 tier-1 vital signs.

Studies have shown a lag time between establishment of a non-native plant, to when it becomes invasive (Richardson and Pysek 2006). Thus, a plant that is not recognized as an invasive today may indeed be on the list in a few decades. As such, early detection of non-native invasive plants is a high priority. Control or eradication of a non-native invasive plant population, when it is of manageable size, is efficient, cost-effective, and protects resources.

Aspects of two monitoring protocols are proposed for SIEN parks: (1) one examines the status and trends of non-native plants and establishing better operational procedures for prioritization of management, and (2) the other looks at methods for early detection.

The monitoring of the status and trends of non-native invasive plants need to be dynamic. There are different levels of invasiveness—some species, such as dandelions, ranked lower in priority, while others, such as Himalayan blackberry ranked as high (Gerlach et al. 2003). With collaborators, the Network’s Non-native Plant Workgroup is working on

developing new ranking criteria and mechanisms for keeping the list current.

As mentioned above, dynamic ecological factors—particularly those affected by SIEN stressors—can modify the susceptibility of a community to invasion (Mack and D’Antonio 1998, Lonsdale 1999, Davis et al. 2000). We present details (narrative and conceptual models) regarding invasion susceptibility, below.

Sub-Model: Non-native Plant Populations — Invasion Susceptibility

Introduction

Sierra parks have been invaded by numerous non-native plant species. Some are wellknown invaders in other areas (e.g., cheatgrass—*Bromus tectorum* in the Great Basin), and consequently we know about their invasion ecology and effects on invaded ecosystems (Gerlach et al. 2003). Others have not been well investigated, and their effects are relatively unknown. Thus, we usually treat each invasive species as if it has a unique ecology. Not all plant communities have been invaded by non-native plants (Gerlach et al. 2003). In addition, the qualities that make a plant community susceptible to colonization by non-native plants (i.e., invasibility) are not generally understood (Rejmanek and Richardson 1996). Our primary interest in monitoring non-native plants is to improve early detection of both new taxa that have not yet arrived in SIEN parks and new populations of non-natives that already occur in parks.

Although the ecology of invasion has received much attention in the last several decades, we still lack an all-encompassing theory of invasion (Davis et al. 2000, Davis and Thompson 2000), nor is there agreement on the terminology of invasion (Davis and Thompson 2000); (Daehler 2001); (Rejmanek et al. 2002). Here, we adopt the terminology of (Richardson et al. 2000) to describe the process of naturalization and invasion by non-native plants. The conceptual model we present is based on that proposed by (Davis et al. 2000).

The process of invasion can be most

simply described as the sequential occurrence of three phases: introduction, naturalization, and invasion. Introduction means that the plant or its propagules have been transported across a significant geographical barrier. Many introduced plants may survive for short periods (called casuals or waifs) but do not persist unless repeatedly introduced. Naturalization occurs when introduced individuals reproduce regularly, overcoming any environmental or reproductive barriers, to establish a population sufficiently large that it is not subject to extinction by environmental variability. The length of time the population must persist to qualify as naturalized is not defined, but might be at least 25 years (see (Richardson et al. 2000), p. 99). Finally, invasion is the spread of the plant into areas distant from the site(s) of introduction. Invasion requires that the plant overcomes any barriers to dispersal in the new area, and can survive the abiotic environment as well as biotic interactions in the new area.

Introduction of species into the parks depends in part on whether surrounding communities (proximity of source) have been invaded, and on the vectors available to transport the plant (or its propagules) into the parks. Natural transport vectors, such as wind and animals, can move propagules into the parks. Plants or propagules may also be transported by human activities that import contaminated materials into the parks. These materials may include equipment, soil, sand, gravel, hay, straw, cultivated plants, car tires, and shoes.

Once propagules or plants of potentially invasive species have arrived in parks, their naturalization, and subsequent invasion, may occur. Alternatively, propagules or plants may arrive in the parks from surrounding areas in which the invasive species is already naturalized. Thus, introduction to the parks can be considered invasion.

Our conceptual model of invasibility describes the process by which an exotic species may become established in an otherwise natural plant community. The model focuses sequentially on the roles of resource availability, temporal fluctuations in resources, and differences

among communities in invasibility.

Invasibility of a Community

Below we describe scenarios influencing the invasibility of a community. For this model, (see Figure F-27), we consider the resources used by plants to be water, nutrients, and light (Davis et al. 2000). When resource uptake is very close to resource supply—the isoline—we expect competition to be strong and resource availability to be low. Thus, an invading plant would probably not persist. However, invasibility may increase if resources become more available. Resources can become more available either through an increase in supply (arrow A), a decrease in uptake (arrow B), or both. There are many factors that may change resource availability. Those that may be important for Sierra Nevada plant communities are listed in Table F-5.

Although the spatial extent of most of the factors in Table F-5 is very broad, some disturbances do act at local extents to decrease resource uptake. This might include natural perturbations such as gopher mounds and human-caused disturbances such as road edges and trails.

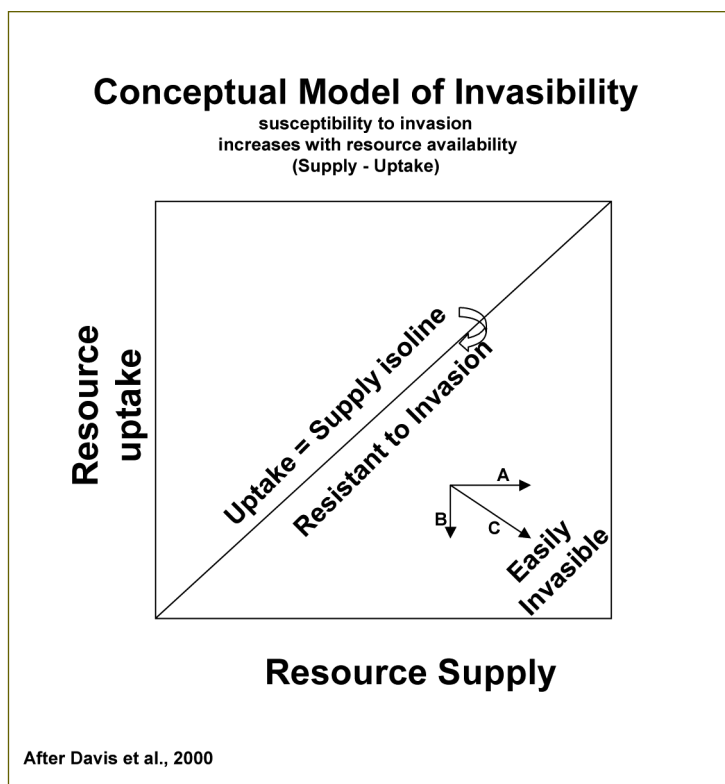


Figure F-27. Community invasibility: relationship to resource uptake and supply. After Davis et al. 2000.

Table F-5. Factors that result in changes in resource availability and subsequently in invasibility of plant communities.

| FACTORS THAT FAVOR AN INCREASE IN RESOURCE SUPPLY (ARROW A) | FACTORS THAT DECREASE RESOURCE UPTAKE (ARROW B) |
|--|--|
| <ul style="list-style-type: none"> Increased precipitation—increased water supply | <ul style="list-style-type: none"> Decreased precipitation—decreased water supply |
| <ul style="list-style-type: none"> Climate change toward more moderate temperatures | <ul style="list-style-type: none"> Climate change toward more extreme temperatures |
| <ul style="list-style-type: none"> Fire—increased mineralization, reduced overstory (increased light on forest floor) | <ul style="list-style-type: none"> Fire—kills or maims plants |
| <ul style="list-style-type: none"> Nitrogen deposition—fertilizer effect | <ul style="list-style-type: none"> Excess pollution—toxicity |
| | <ul style="list-style-type: none"> Disturbance that kills or maims plants, e.g., increased herbivory, diseases, avalanches, grazing, floods |

Invasibility Windows

As with factors that contribute to resource supply and uptake, resource availability usually fluctuates with time. Fluctuations in resource supply with season are likely to be overlain by shorter-term fluctuations due to local disturbances. Periods of greater resource availability typically lead to reduced competition, and thus represent “invasibility windows” for introduced species (Figure F-28). In this hypothetical example, uptake is near supply until a disturbance occurs that reduces uptake. This leaves a gap between supply and uptake for a period of time that defines an invasibility window.

Invasibility windows vary in magnitude (i.e., the difference between supply and uptake) and in length. Also, introduced species are likely to differ in the required thresholds of magnitude and length of the invasibility window necessary for the species to become naturalized. An invulnerable window for one species may not be for another species. In addition, if an introduced species requires resources at a higher level than are available in the invasibility window, it may not naturalize. For those introduced species that do naturalize, the frequency of occurrence of suitable invasibility windows must be sufficient for the species to complete the process of invasion by spreading to other sites. The spatial arrangement of these sites on the landscape may influence the ability of the species to spread (With 2002). For example, for a species that invades through disturbed habitats the extent

and connectivity of these habitats must be sufficient to allow spread.

Invasibility and Plant Community Type

An application to Sierra Nevada plant communities contrasts hypothetical scenarios for two different plant communities: (1) a low elevation annual grassland, and (2) a high elevation alpine fell-field (Figure F-29). The annual grassland community of the Sierra Nevada is already highly invaded, with new species continuing to naturalize. This community has relatively high resource supply and favorable growing conditions (except for the hot, dry summer season). A disturbance during the growing season that drastically reduces resource uptake can leave a large invasibility window. Hypothetically, a larger invasibility window should allow a larger number of species to exploit that window. In contrast, the alpine community has a much lower level of resource uptake and supply than an annual grassland. A disturbance during the growing season (Figure F-29) decreases resource uptake, but not by the magnitude found in an annual grassland. The invasibility window in the alpine community is small compared to the annual grassland; thus, few introduced species are able to exploit it.

This conceptual model of invasion has some deficiencies. Foremost among them, it does not accommodate interactions among species other than competition. For example, it does not account for introduced species that have deleterious effects on their neighbors (e.g., allelopathy—see (Bais et al. 2003). It also fails to generalize to animal invasions, although the model is suitable for some aspects of animal invasions. For example, some invasive animal species exhibit aggressive behavior, which is not included in this conceptual model.

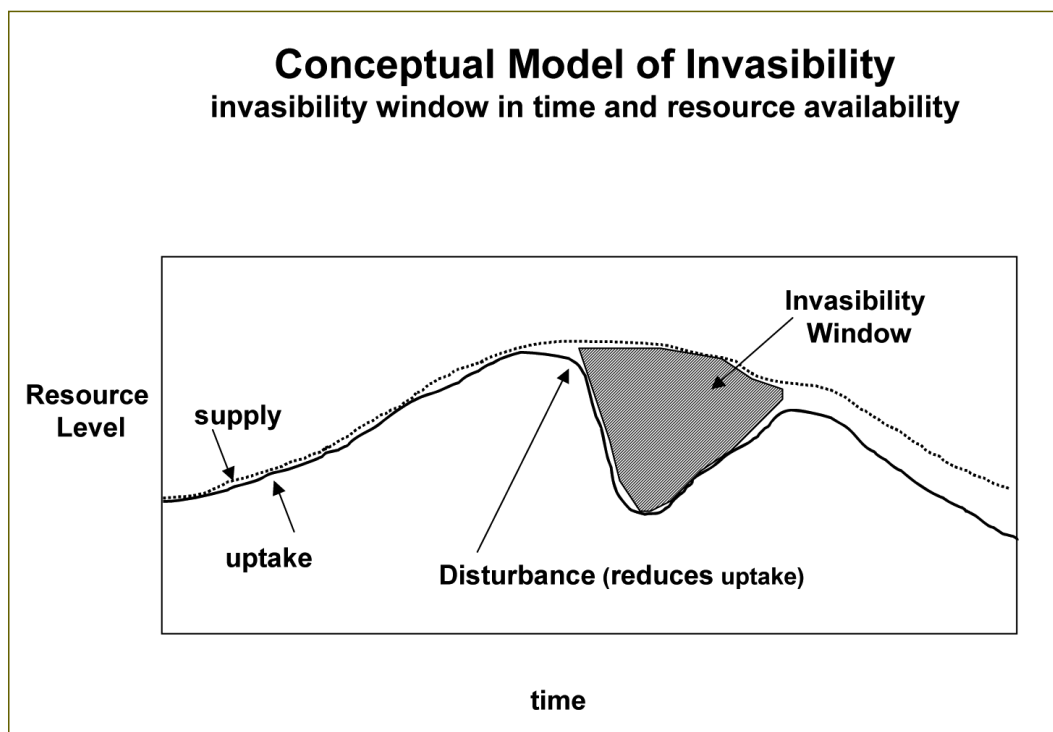


Figure F–28. Resource availability and windows of invasibility in time.

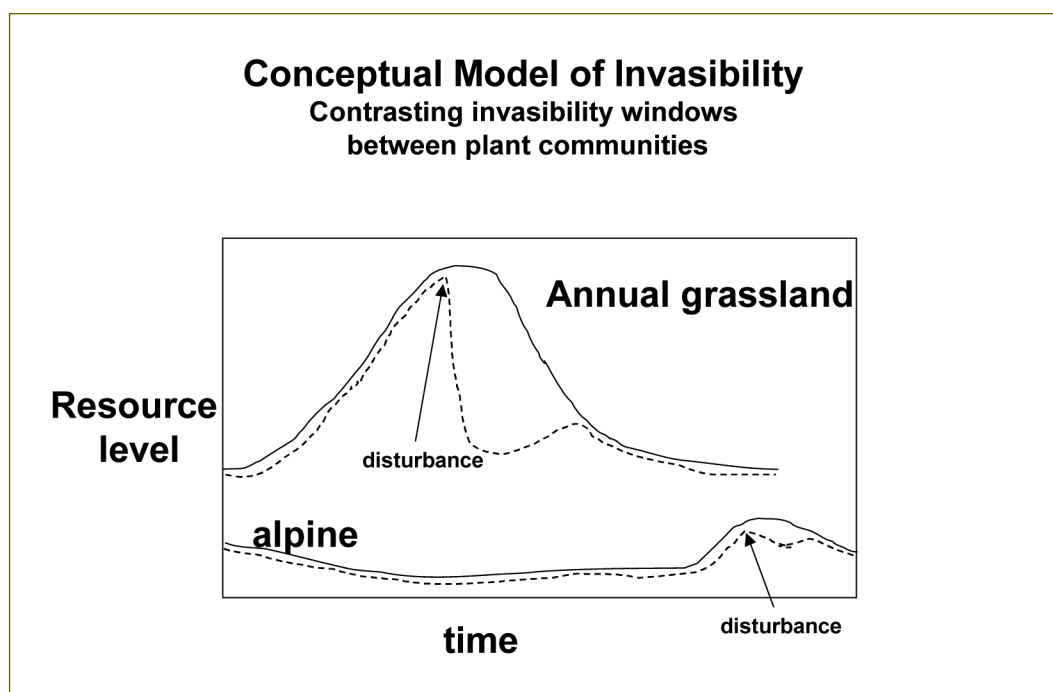


Figure F–29. Conceptual diagram of invasibility, contrasting two plant communities—annual grassland and alpine—that differ in resource levels.

Model: Bird Populations

Introduction

Sierra Nevada Network parks provide birds over 658,000 hectares (1,600,000 acres) of unusually diverse habitats, ranging from gently sloping foothill grasslands, through chaparral/oak woodland and giant conifer forests, up to windswept alpine wetlands and peaks. While none of the approximately 200 bird species that breed, winter, or migrate through the Sierra Nevada are unique, the key to its exceptional bird diversity is its extreme elevation gradient and corresponding habitat diversity. The western slope's elevation gradient spans over 14,000 feet—from the lower foothills to the top of Mt. Whitney—and supports the most diverse assortment of terrestrial habitats and birds in California (Beedy 1985).

Accordingly, our Mediterranean climate varies dramatically from the mild winters and hot dry summers that characterize the foothills, through wetter and cooler mid-elevations, up to harsh long winters and short summers in sub-alpine and alpine areas. Since birds are inextricably tied to the passage of seasons, species occupying different elevations follow radically different annual schedules. In recognition of the Sierra Nevada's bird diversity and critical breeding, stopover, and wintering habitats, Sequoia, Kings Canyon, and Yosemite National Parks, and a few other large areas in the Sierra Nevada, have been designated by the American Bird Conservancy as "Globally Important Bird Areas."

Status of Bird Populations

Many populations of birds and other species are now threatened or endangered, or will likely become threatened soon, as a result of anthropogenic climatic and environmental changes (Terborgh 1989). The improved ability of scientists to document species population trends has led to long-term monitoring programs to monitor the health and status of populations, and to investigate the causes of observed population changes. North American Breeding Bird Survey data indicate that numerous bird species exhibit declining long-term population

trends in the Sierra Nevada region. Data from the Sierra Nevada Network MAPS (Monitoring Avian Productivity and Survivorship) program in the parks' wetland habitats have shown declines in many breeding populations of birds. Analyses reveal negative trends in 13 species; and, adult birds of all species (pooled) represent a highly significant decrease, suggesting that populations of birds in Yosemite have been reduced by 23% over the last 13 years (Pyle et al. 2006). Over half the declining species exhibited low reproductive success, indicating that population dynamics on their Sierra Nevada breeding grounds is a limiting factor to these species' survival.

Stressors

Researchers have identified five main categories of stressors faced by birds in Sierra Nevada Network parks (Figure F- 30) : (1) anthropogenic climate change (2) habitat fragmentation, loss, and insularization, (3) atmospheric pollution, (4) altered fire regime, and (5) invasive species (DeSante 1995, Graber 1996) SIEN Bird Workgroup 2006, pers. comm.).

Anthropogenic Climate Change

Over 140 studies have shown that global warming is correlated to biological change and several of these studies have revealed that as temperatures increase, the geographical ranges of numerous species have shifted poleward or moved to a higher elevation (Root et al. 2003, Root et al. 2005). Concurrent with these studies, the recent Grinnell resurveys across the Sierra Nevada detected many bird species ranging higher in elevation than observed 80 years earlier by Grinnell and his colleagues.

Habitat fragmentation, Loss, and Insularization

Habitat fragmentation and loss, including increasing exurban development with its concomitant increases in land conversion, is one of the biggest problems faced by birds today, and has contributed to the majority of species declines (Neotropical Migratory Bird Conservation Act 2000). The most endangered songbird in the Sierra Nevada, the Willow Flycatcher,

is rapidly disappearing because of land use practices (e.g., grazing, agriculture) that have denuded or destroyed their riparian habitat. Habitat degradation on a regional scale probably affects the viability of bird populations on relatively intact habitats managed inside the parks. Nearctic-Neotropical migratory passerine birds are exhibiting the most severe population declines because they face habitat destruction and degradation during migration stopover and on both wintering and breeding grounds.

Atmospheric Pollution

The deposition of atmospheric pollutants in California's Sierra Nevada Mountains has resulted in the degradation of ecosystems (Duriscoe 1987, Unger 1989) and is thought to play a role in the declines of several wildlife populations (Davidson 2004, Fellers et al. 2004). Environmental pollutants, such as organophosphorous pesticides and ozone, travel upslope from the heavily developed San Joaquin and Sacramento Valleys due to prevailing winds (Zabik and Seiber 1993, LeNoir et al. 1999, Fancy and Gross 2004). The pollutants enter the Sierra Nevada ecosystem via wet and dry deposition, ultimately making their way into the food chain (LeNoir et al. 1999).

Altered Fire Regime

The Sierra Nevada ecosystem was historically dependent upon frequent fire. Fire created complexity across the landscape by opening forests for shrub communities and creating snags, logs, and a varied-age plant structure - all critical features that support diverse and abundant wildlife. Fire exclusion from the Sierra Nevada has contributed to long-term shifts in habitat composition and structure (Gruell 2001) which has negatively affected a diversity of birds, for example, Olive-sided Flycatcher which favor open forest with snags and scattered trees, Brown Creeper and Pileated Woodpecker which rely on older forests with large-diameter trees, and Black-backed Woodpecker which depends on burned forest.

Invasive Species

Invasive species include both introduced

and native human commensal species that have expanded their range in the Sierra Nevada because of increased food supplies from stables, picnic areas, campgrounds, and residential areas. Introduced species, such as cavity nesting European Starling and House Sparrow, compete with native species for nest holes, and in some areas, such as Lee Vining Canyon, have reduced native populations of Violet-green Swallows, House Wrens, and Mountain Bluebirds (Leland and Carter 1985, Gaines 1988). Native human commensals (native pest species) have increased historically, both in extent of range and abundance (Marzluff 2005) and include nest predators, the Brown-headed Cowbird, and generalist species. Nest predators, such as Common Raven, Steller's Jay, and Western Scrub-Jay, take both eggs and young from nests. The nest parasite, Brown-headed Cowbird, lays their eggs in the nests of small songbirds such as vireos, flycatchers, and warblers, who raise the cowbird young usually at the expense of their own. Generalist species include American Robin, Northern Mockingbird, and blackbirds which are more numerous near campgrounds and residential areas and eventually may limit the size of other native songbird populations if food and nest sites become limited resources.

Vital Sign

Birds are an appropriate indicator-species of local and regional change in terrestrial ecosystems because their ecology and biology integrates the effects of numerous stressors (Canterbury et al. 2000). Because of their high body temperature, rapid metabolism, and high ecological position on most food webs, birds are excellent integrators of the effects of local, regional and global environmental change on terrestrial ecosystems. Furthermore, their abundance and diversity in virtually all terrestrial habitats, diurnal nature, discrete reproductive seasonality, and intermediate longevity facilitate the monitoring of their population and demographic parameters (DeSante et al. 2005). Bird populations are a scientifically viable vital sign and surrogate for evaluation of network

ecosystem condition for several reasons:

- Birds occupy a wide diversity of ecological niches in the parks
- Birds are conspicuous, easily observable, and monitoring is cost effective
- As secondary consumers (i.e. insectivores), birds are sensitive indicators of environmental change
- By managing for a diversity of birds, most other elements of biodiversity are conserved and bird monitoring can prevent future listing of declining species by identifying problems and solutions early;
- Knowledge of the natural history of many bird species has a rich basis in literature
- All units in SIEN have a strong foundation of inventory data upon which to build future monitoring efforts
- Monitoring Avian Productivity and Survivorship (MAPS) has occurred at all parks for varying numbers of years and time periods, including at one station in Yosemite (Hodgdon Meadows) for 14 years

Measures

In addition to population trends (distribution and abundance), effective management of birds should include assessment and monitoring of vital rates (primary demographic parameters) (DeSante et al. 2005). Environmental stressors and management actions affect vital rates directly, usually without time-lags. Vital rates are essential for understanding a) the stage of the life cycle where population change is being effected, b) health and viability of populations, and c) habitat quality (DeSante et al. 2005). DeSante et al. (2005) identified six vital rates upon which management should be based: (1) productivity, (2) survival of young, (3) recruitment of young, (4) annual survival of adults, (5) site fidelity, and (6) immigration. By identifying proximate demographic cause(s) of bird population changes, management guidelines may be formulated to reverse population declines and to evaluate the effectiveness of the management actions implemented.

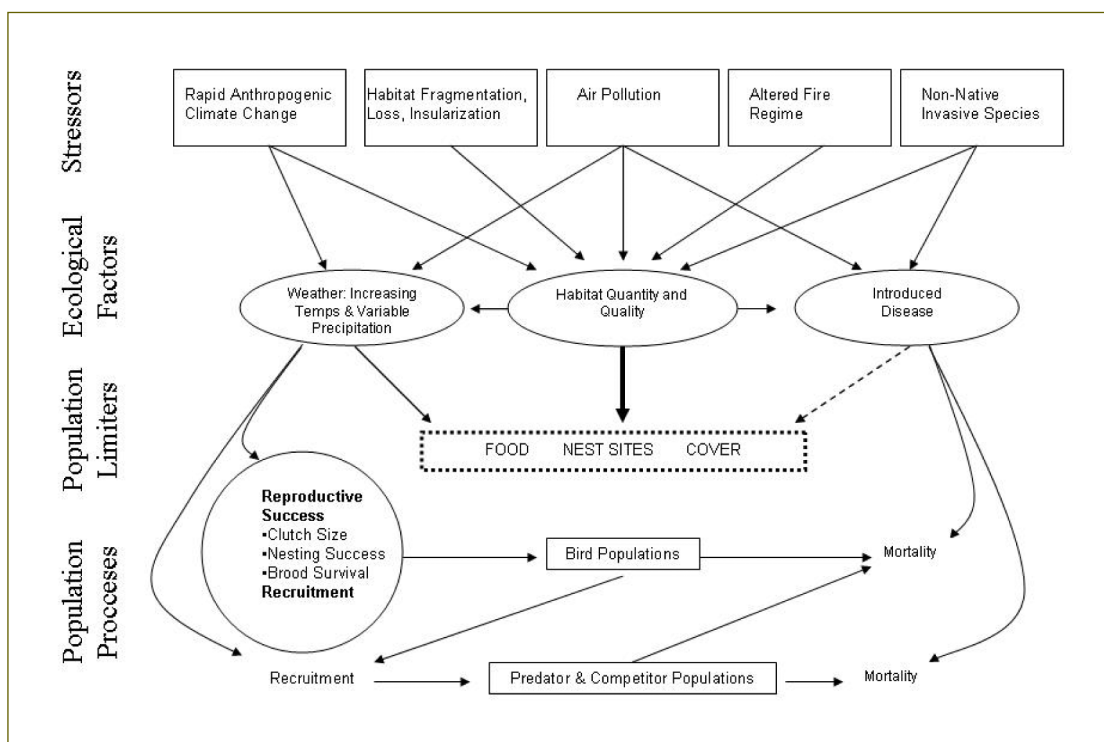


Figure F-30. Bird populations conceptual diagram, including principle interactions of stressors, ecological factors, population limiters, and population processes.

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